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On the Relationship between Migmatization and Structure in Mid-Strathspey

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ABSTRACT

The distribution and form of the products of migmatization in the area are described and the close relationship between migmatization and folding in time and space is demonstrated. Synoptic diagrams of the linear structural elements for various parts of the area are given. The sheaves of β-axes, small folds and lineations widen with increase in migmatization, presumably due to increasing mobility of the rocks during the migmatization process.

INTRODUCTION

IT has been stated, for example by Wegmann (1929, p. 106), that increasing mobility of rocks during deformation results in an increasing spread of the sheaf of axial structural elements but, to the best of the writer's knowledge, no examples of such an increase in spread have hitherto been published. During the course of detailed structural and petrological work in Mid-Strathspey the synoptic treatment of large numbers of structural measurements made it clear that Wegmann's qualitative statement was supported quantitatively. This paper sets out the evidence obtained and some aspects of migmatization in its wider structural setting are also discussed.

The geology of the area has been described and the petrology briefly summarized in the Geological Survey Memoirs for Sheets 74 and 84 (Hinxman and Anderson, 1915; Horne, 1923). More recently structural work has been carried out on all scales from microscopic to regional (McIntyre, 1951; McIntyre and Turner, 1953).

The solid rocks of the area are quartzo-feldspathic and pelitic gneisses of the Moine Series, with minor calc-silicate rocks, marbles, and amphibolites. These metamorphic rocks belong to the lower amphibolite facies. Syntectonic and post-tectonic granites are emplaced in the rocks of the Moine Series. According

to Kennedy (1946, Text-figs. 2 and 3) the southern part of the area lies within a zone of regional injection, i.e. migmatization.

Migmatization

Throughout most of the area, but particularly in the south-west along the Spey–Dulnain watershed, the rocks of the Moine Series have suffered folding and migmatization. Both quartzo-feldspathic and pelitic rocks are migmatized in the south-west but elsewhere migmatization is slight and tends to be confined to pelitic and semi-pelitic rocks.

In general the mineral composition of the quartzo-feldspathic and pelitic gneisses is independent of their state of migmatization. The quartzo-feldspathic gneisses ("granulites") are fine to medium in grain and are usually thinly banded. Their texture is granoblastic, quartz, oligoclase, microline, biotite, and muscovite being the principal constituents. The pelitic gneisses vary considerably in grain size and are characterized by an abundance of biotite and muscovite with subsidiary quartz, andesine, and microcline. Garnet occurs sparsely in both migmatized and non-migmatized rocks. A constant feature of both quartzo-feldspathic and pelitic gneisses is the occurrence of ragged and irregular intergrowths of plagioclase with microcline. Where the microcline occurs as isolated patches in the plagioclase these patches are in optical continuity with each other, and one of the twin axes of the microcline coincides with the albite twin axis of the plagioclase. Areally, and therefore volumetrically, there is a complete gradation from plagioclase with a few per cent included microcline to microcline with a little included plagioclase but the complete gradation is not, however, present in all specimens. The lack of displacement of the twin lamellae of the plagioclase by the microcline suggests that the latter is replacive, i.e. there has been slight potash metasomatism.

Along the Spey–Dulnain watershed the effects of migmatization take three forms, of which the second is by far the most common.

(1) At a few localities—apparently distributed at random—the quartzo-feldspathic gneisses are granitic in character, as has already been noted in the Memoir (Hinxman and Anderson, 1915, p. 21). The rocks are massive, and, in contrast with the grey enclosing gneisses, are pink in colour and contain randomly oriented, scattered mica flakes. In thin section they are seen to contain quartz, oligoclase, microcline and small amounts of biotite and muscovite (in order of decreasing abundance), and are virtually indistinguishable from the normal banded gneisses.

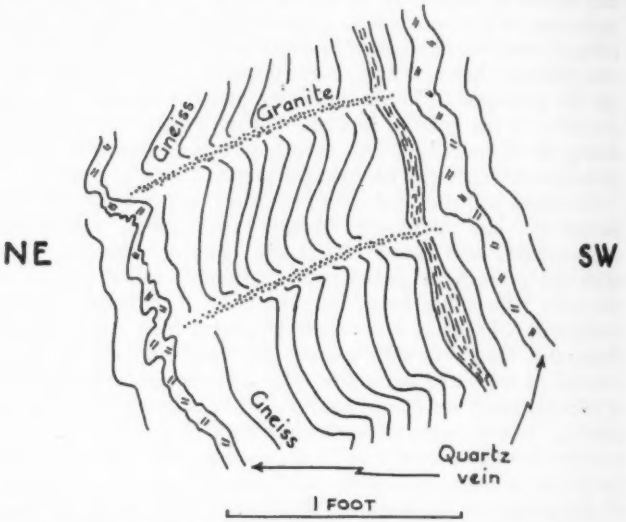
(2) The gneisses contain abundant coarse quartzo-feldspathic

bodies, concordant with the foliation, in the form of lenses, layers, knots, rods, and ptygmatic veins, all of which are either elongate parallel to, or contain a linear structure parallel to, the fold axis. Where the foliation is steep or intensely folded these quartzose bodies are most abundant and conspicuous, commonly occurring in the crests and troughs of small folds. Small quartzo-feldspathic eyes characterize many but not all of the micaceous layers. Every gradation in size is found from eyes a quarter of an inch across to lenses up to a foot thick. The most common occurrence of the bodies is as single or interconnecting groups of lenses, sometimes haphazard in distribution, sometimes confined to a particular layer. The non-transgressive nature of the bodies and the parallelism of their linear and planar structures with the structures in the gneisses indicate that the lenses were produced during the deformation and assumed forms controlled by the deformation. They can be regarded as syntectonic pegmatites.

The lenses and rods consist for the most part of quartz accompanied by less abundant feldspar (microcline, microcline-microperthite, and calcic oligoclase). Biotite, muscovite, and small red crystals of garnet are occasionally found. Some of the more feldspathic knots have biotite-rich margins. Closely contiguous thin layers are usually separated by a much thinner biotite-rich layer. In thin section the lenses contain the same minerals as are found in the enclosing gneisses but the proportion of micas is much lower and quartz is more abundant than in the gneisses. Intergrowths of microcline with plagioclase are more common in these bodies than in the gneisses; in both rock types the mutual relationships of the two minerals suggest replacement of plagioclase by microcline. The eyes of the augen-gneisses are seldom single feldspar crystals but tend to be formed of mosaics of quartz and feldspars of about the same grain size as the rest of the rock.

(3) Thin impersistent sheets of granitic rock are developed along slip surfaces inclined at a high angle to the foliation and banding of the rocks (Text-fig. 1). The slip surfaces are formed by flexures of the foliation surfaces, and the axes of these flexures are parallel to the axes of near-by small folds; the foliation and slip surfaces intersect in a line parallel to the fold axis. These sheets have only been observed south of the River Dulnain, where the other forms of migmatization are also well developed, and they are best displayed in the steeply dipping gneisses of Creag an Fhithich and Stac an Toisich on the watershed. The sheets dip south-east but are not strictly smooth as the granite is irregularly distributed and sometimes tends to be developed for a

little distance along the quartzose bands of the gneiss, leaving biotitic septa projecting from the gneiss into the granite. The maximum dimensions of the sheets are about 1 inch thick and 3 feet across, the observed extension parallel to the fold axis being about 5 feet. Nowhere have these sheets been seen to cross the quartzose bodies described above. One example was noted in which a thin sheet of granite was found along the axial plane of a small fold. The relative displacement of the foliation on either



TEXT-FIG. 1.—Granite formed along slip surfaces in quartzo-feldspathic gneisses, Stac an Toisich. The gneiss also contains syntectonic concordant quartz veins.

side of the slip surfaces is slight and dies out laterally. There are many incipient slip surfaces which have escaped granitization. The sense of rotation inferred from the slip surfaces is consistent with the sense of rotation shown by the majority of folds in the area. It can thus be inferred that the slip surfaces formed during the general deformation.

Petrographically the material of these thin sheets consists of a mosaic of quartz, sub-idiomorphic oligoclase, some microcline, and small quantities of muscovite and red-brown biotite. These minerals are indistinguishable in properties and appearance from the chief constituents of the gneisses, except that the plagioclase

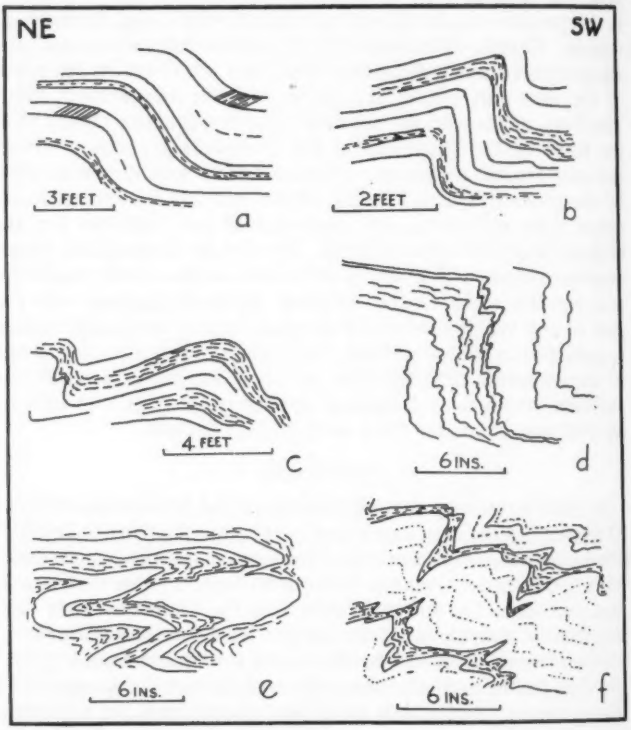
of the granite is slightly more sodic in composition and more highly altered than that of the nearby gneiss. Feldspar is slightly more abundant in the sheets than in the gneisses, whereas the latter are finer in grain.

The evidence outlined above clearly shows a close relationship in time and space between the deformation of the gneisses and the formation of the various quartzo-feldspathic bodies whose presence distinguishes the gneisses as migmatites. The migmatization was syntectonic. A large development of felsic material in the gneisses can be directly correlated with a high intensity of folding. Slightly deformed and non-migmatized rocks containing recognizable relict sedimentary structures are found in the north of the area but not in the south (writer's unpublished data). The form of the various quartzose bodies compares closely with the form of the structures in the surrounding gneisses. Felsic material tended to become concentrated in localities controlled by the structures then forming where, possibly because of lower stress than elsewhere, the environment was suitable for the crystallization of such material. The briefly summarized petrographic evidences of similarity in mineral content of the pegmatitic and granitic rocks to the enclosing gneisses, together with the lack of any visible feeders for the multitude of small acid bodies, suggest that in Mid-Strathspey the migmatization process was one of metamorphic differentiation in which the felsic material was mobilized from the pre-existing neighbouring rocks with little or no addition of matter from more distant sources.

Structure

In Mid-Strathspey the regional dip of the foliation is at about 30 degrees to the east, south-east, or south, according to locality. The linear structural elements, which here comprise β-axes, small folds and lineations, plunge at about 30 degrees to the east, south-east, or south. The structural data from the whole area have been statistically treated, in particular the linear structural elements. In the manner suggested by Wegmann (1929) and Sander (1948) the area has been divided into sub-areas to test the homogeneity of the fabric. β-diagrams have been constructed for numerous sub-areas and the resulting β-axes are considered jointly with the small folds and the lineations. Each β-diagram consists of from 10 to 20 measurements of the foliation; the mutual intersections of the foliation mark a distinct β-axis in each diagram, although some diagrams have a relatively weak maximum. The range of the concentrations of β-maxima is from 15 per cent to 45 per cent per 1 per cent area. In some sub-areas the constancy

of the regional dip of the foliation made it impracticable to determine a β-axis. The number of β-axes is relatively higher, the sub-areas are smaller, and variation in homogeneity is thus more readily detected where folding is strong than where the foliation has a constant dip. Determination of the fold axis by the β-method applied to small sub-areas gave essentially the same result as was obtained by McIntyre (1951) who used a π-diagram bearing measurements from a large tract of country in Mid-



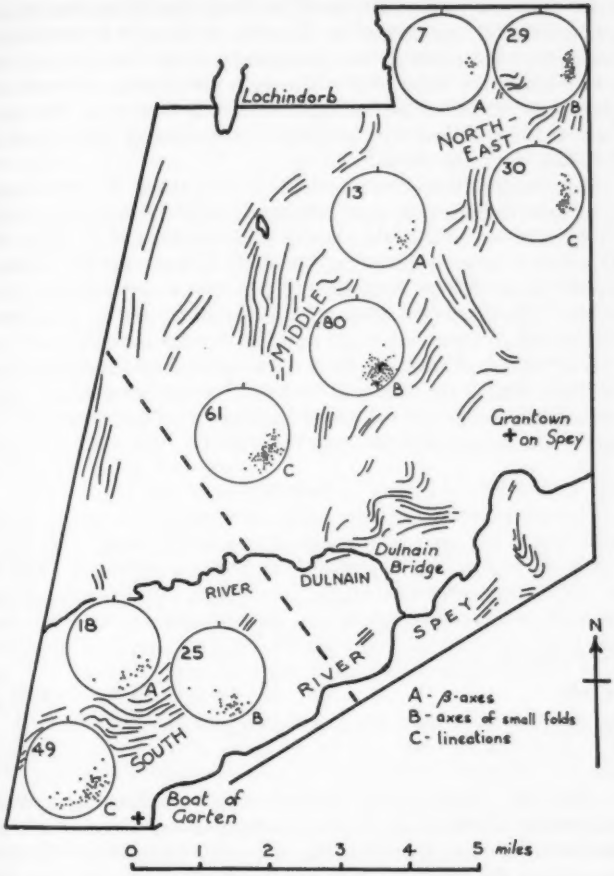
TEXT-FIG. 2.—Profiles of folds in Mid-Strathspey showing in a generalized fashion the progressive increase in the plasticity of the style from the north-east to the south-west of the area (*a–f*).

a. Headwaters of the Allt Breac;

b. South of Carnloch;

c. Laggan Hill;

d, e, f. Creag an Fhithich.



TEXT-FIG. 3.—Synoptic diagrams of β-axes, small folds, and lineations from each of the three districts superimposed on a structural sketch map. Structure shown by form lines of the foliation strike; regional dip to the east and south-east. Number of axes in top left-hand corner of each diagram. Broken line marks the onset of general migmatization.

Strathspey and whose study was on a larger scale than that considered here.

The fold style on all scales is monoclinal or slightly recumbent, the folds being overturned from the north-east. On the whole the

style does not vary greatly from one rock type to another at the same locality. As shown in Text-fig. 2 there is a progressive increase in the plasticity and complexity of the style towards the south where the sense of overturning is sometimes equivocal and flagrantly disharmonic folding is relatively common. Yet even here the monoclinal style persists in well-exposed folds of up to 150 feet in profile depth.

To demonstrate synoptically the variation in the linear structural elements the area has been divided into three districts designated north-eastern, middle, and southern, for which the Grantown–Forres railway and the River Dulnain are the dividing lines. Each district contains between seven and eighteen sub-areas. The small size of the north-eastern district is occasioned by the lack of exposures to the north of the area described.

The results of plotting the β-axes, small folds, and lineations for each district are shown in Text-fig. 3 (lower hemisphere equal area projections), and the apical angles of the sheaves or cones of the different elements are listed in Table 1.

TABLE 1.

District	Number of diagrams	Apical angle, cone of β-axes	Apical angle, cone of folds	Apical angle, cone of lineations	Average value of β-maxima
North-Eastern	7	14°	34°	52°	32%
Middle	13	56°	60°	77°	26%
Southern	18	95°	108°	120°	21%

The apical angle given is that of the smallest cone which completely contains all the axes concerned and its value can be measured directly from the Schmidt net. The axis of the cone containing the elements does not, however, necessarily coincide with the point maximum of the elements which is usually shown by contouring the diagram. The cone gives a measure of the dispersion of the elements whereas the point maximum or density distribution tends to emphasize their degree of concentration. It will be noted that the angular spread of all three elements increases markedly to the south. Moreover, in each district the β-axes form the closest sheaf, followed in order by the small folds and the lineations. The spread is greater in the plane of the foliation than at right angles to it, indicating that the trend of the

axes is more variable than their plunge. It is thus clear that, their small numbers notwithstanding, the β-diagrams—representing the attitude of the foliation and thus the homogeneity of the structure on the scale of the sub-area—are more reliable indicators of regional homogeneity than diagrams of small folds and lineations, although in Mid-Strathspey the last two give a good indication of the regional fold axis. With widening of the sheaf of elements to the south, the average value of the β-maxima for each district decreases regularly (Table 1), indicating an increasing departure of the foliation surfaces from the cylindroidal within the individual sub-areas of that district. The variation in homogeneity does not here appear to be markedly affected by the presence of different rock types, as the middle district contains a wide variety of both competent and incompetent types.

The apical angles of the cones of elements are to be considered not as absolute but as relative or comparative indicators of inhomogeneity which show the general trend to dispersion. Account must also be taken of the number and type of axes contained within each cone.

Weiss (1954) has suggested that a spread of β-maxima can result from the presence of truly lensoid bodies produced by axial flow along the direction of the fold axis but there is no indication that lensoid bodies are present or that axial flow has taken place in the area under discussion. The correlation of structural inhomogeneity with abundance of mobilized material supports Wegmann's (1929) assertion that the degree of mobility or competency of different rocks directly determines the degree of spread of their axial elements.

Concomitant with the widening of the sheaf of linear elements there is a swing in the trend of the regional fold axis from east through south-east towards south-south-east. The reason for this change of trend is outside the scope of this paper. There is no evidence at present to suggest whether or not this change can be correlated with the degree of migmatization or is a purely tectonic feature.

When the first indications of distinct migmatization of the rocks on a large scale are plotted on a structural map of Mid-Strathspey the migmatite boundary or " front " is seen to transgress the structural levels obliquely (Text-fig. 3). Therefore migmatization has not been controlled entirely by tectonic depth, progressively higher structural members being migmatitic towards the south-west. As no metamorphic zone boundary crosses the area it is not possible to determine whether the isograds are parallel to the migmatite front or to a particular structural level or to neither.

Conclusions

The migmatization is syntectonic and its products take the form of predominantly quartzose pegmatites, lensoid in profile and concordant with the foliation, together with minor sheets of granitic rock along slip surfaces oblique to the steep foliation. It is inferred from the evidence that the process of migmatization is a variety of metamorphic differentiation rather than a process of injection.

It has been found possible to correlate the relative abundance of discrete bodies of felsic material in the gneisses, i.e. the degree of migmatization, with increase in (*a*) the intensity of folding; (*b*) the plasticity of the fold style; and (*c*) the degree of structural inhomogeneity both in sub-areas and districts; and thus presumably with a general increase in the mobility of the rocks during folding. The evidence given above constitutes statistical proof of Wegmann's statement that the dispersion of the π-poles from the great circle increases as the migmatization of the rocks becomes more intense. It is considered likely that this conclusion is generally applicable to metamorphic terrains.

Acknowledgments

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References

Hinxman, L. W., and E. M. Anderson, 1915. The geology of Mid-Strathspey and Strathdearn. *Mem. Geol. Surv. U.K.*

Horne, J., 1923. The geology of the Lower Findhorn and Lower Strathnairn. *Mem. Geol. Surv. U.K.*

Kennedy, W. Q., 1946. The Great Glen Fault. *Quart. Journ. Geol. Soc.*, cii, 41–76.

McIntyre, D. B., 1951. The tectonics of the area between Grantown and Tomintoul (Mid-Strathspey). *Quart. Journ. Geol. Soc.*, cvii, 1–22.

McIntyre, D. B., and Turner, F. J., 1953. Petrofabric analysis of marbles from Mid-Strathspey and Strathavon. *Geol. Mag.*, xc, 225–240.

Sander, B., 1948. *Einführung in die Gefügekunde der Geologischen Körper*, Part I, Vienna and Innsbruck.

Wegmann, C. E., 1929. Beispiele tektonischer Analysen des Grundgebirges in Finnland. *Bull. Comm. géol. Finlande*, lxxxvii, 98–127.

Weiss, L. E., 1954. A study in tectonic style. *Univ. Calif. Publ. Geol. Sci.*, xxx, 1–102.

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A Palaeomagnetic Investigation of the Lundy Dyke Swarm

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ABSTRACT

The directions of the natural remanent magnetization of samples collected from dykes on Lundy have been measured and related to those of Tertiary lava flows in Northern Britain. Evidence is given suggesting that the dykes are Tertiary and pre-Upper Oligocene in age, and that the geomagnetic field was reversed at the time of their intrusion.

INTRODUCTION

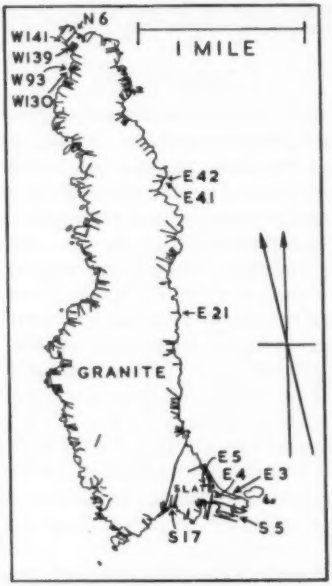
THE Lundy dyke swarm was shown by Dollar (1941) to have petrological affinities with the Tertiary igneous complexes of Ardnamurchan and Mull, whereas the Lundy granites closely resemble the Armorican granites of South-West England. The dykes are essentially restricted to Lundy and, like the Tertiary dykes in Northern Britain, they have a tendency to strike N.W.–S.E. Only one dyke which would appear to be related to the Lundy dyke swarm is definitely known from the mainland of North Devon, and this outcrops at Lee Bay, near Ilfracombe.

Because of the intimate association of the dykes with the granites on Lundy they have also been regarded (Dollar, 1941, p. 76) as part of the same igneous cycle as the granites, rather than belonging to a separate orogeny. Thus the problem of the age of the dykes is whether they are Permo-Carboniferous or Tertiary. It is felt that rock magnetism is sufficiently advanced to be able to assist in resolving this problem as, in Britain, the directions of remanent magnetization of rocks of these two ages are well separated.

Five oriented samples were collected from the dyke at Lee Bay and, under the guidance of Dr. Dollar, 36 samples were collected from 13 dykes on Lundy, together with five samples of the granites. Although a large number of the 150 dykes mapped by Dollar are inaccessible it was possible to sample reasonably uniformly round the island (Text-fig. 1). Dollar has numbered all the dykes mapped on Lundy, the letters N., S., E., and W. referring to the coast on which they occur, and his notation has been followed. Dykes of various composition and of differing strike directions were sampled. In some cases samples of the baked country rock in contact with the dyke walls were collected, and these proved to be most useful. In all cases the samples were of fresh, unweathered rock. Apart from minor faulting the dykes are unaltered.

Magnetic Measurements

Two orientated, cubic specimens were cut from each of the samples on which to measure the direction of the remanent magnetization. The strongly magnetized specimens were measured with a spinning magnetometer originally built by Bruckshaw and Robertson (1948) and modified by Vincenz (1952), and the weakly magnetized ones with an astatic magnetometer similar to that



Text-fig. 1.—Lundy Dykes (after Dollar), showing those sampled.

described by Blackett (1952), and capable of measuring magnetic moments of 5×10^{-7} e.m.u. The two instruments were intercalibrated. The magnetic susceptibility was also measured.

Before measurement every specimen was stored for a month in the present earth's field, oriented as *in situ*. After measurement each one was turned through 180 degrees about an E.–W. axis, to lie for another month, and was then remeasured. This process served two purposes: first, the mean of both measurements removed isothermal and viscous magnetization, leaving only the natural remanent magnetization which was derived from

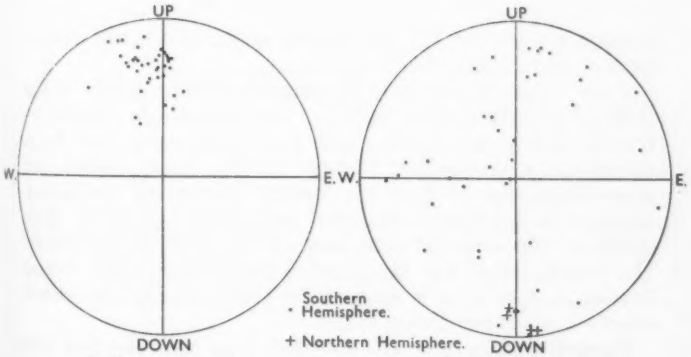
the original thermo-remanent magnetization acquired during the formation of the dyke; second, it is a standard method of testing the stability of the remanent magnetization, since those specimens whose direction of magnetization altered greatly between the two observations are probably unstable.

A further test of stability is afforded by the calculation of the value Q_n, the ratio of natural remanent magnetization to induced magnetization. Dutt (1955) showed that for the Mull lava flows the greater the value of Q_n the greater is the stability of magnetization.

Magnetic Results

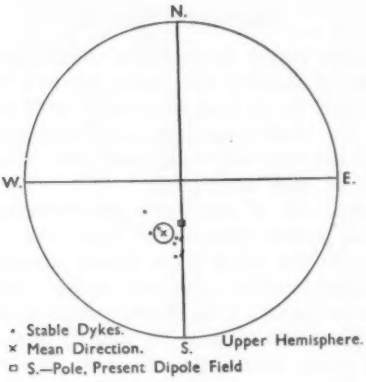
Specimens gave varied directions of magnetization according to their degree of stability but, using the two tests mentioned above, they could be divided into stable and unstable groups (Text-fig. 2). The stable specimens are closely grouped together whilst the unstable ones are widely scattered, in agreement with previous work on rock magnetism.

The magnetizations of the stable specimens are opposed in direction to the present earth's field, and those of the unstable ones appear to be the result of an inverse magnetization which has been modified to differing extents by the continued application of the present earth's field. Since various rock compositions are involved this would support the idea of reversal of the geomagnetic field rather than chemically formed inverse magnetization, particularly when the evidence of the baked contact rock is taken into account.



Text-fig. 2.

Five of the dykes sampled appear to be stable, three partially so, and five are unstable. There is no obvious relation between stability of magnetization and rock composition, as trachytes and dolerites are included in both stable and unstable groups. For an investigation of the age of the dyke swarm the unstable and partially stable dykes must be rejected. In the cases of the dykes E.41 and E.42 (Text-fig. 1), however, samples of contact granite were collected and proved to be magnetically stable so they can be included, even though the dykes themselves are unstable. One



TEXT-FIG. 3.

partially stable dyke, E.5, has a stably magnetized baked slate in contact, and this can also be included.

Table 1 gives the results of the magnetic measurements for the dykes used in the age investigation. The directions of magnetization of these dykes together with their mean value have been plotted on a stereogram, Text-fig. 3. The circle around the mean denotes for the dykes the cone of 33⅓ per cent confidence, calculated using Fisher's statistical method (Fisher, 1953). It is effectively the spherical equivalent of the standard deviation. The magnetism of Lee Bay dyke is included in Table 1 and Text-fig. 3. The dyke is magnetically stable, and is magnetized exactly as the stable Lundy dykes.

The five samples of granite collected, from each of which two specimens were measured magnetically, were weakly magnetized and the limit of sensitivity of the magnetometer was approached.

TABLE 1.

Dyke	Rock Composition	Strike	No. of Specimens	Magnetic Intensity ($J \times 10^{-6}$ e.m.u./c.c.)	Q_n	Declination Ø	Dip I
Lundy:—							
E.4	Trachyte*	N. 146° E.	3	9·5	1·0	N. 181° E.	− 60° UP
E.5	Contact Slate (Quartz Dolerite dyke)	80°	2	5·3	0·4	186°	− 60°
E.41	Contact Granite (Dolerite dyke)	108°	2	18·6	1·6	211°	− 58°
E.42	Contact Granite (Dolerite dyke)	133°	2	2·2	0·7	180°	− 53°
S.17	Crinanite	100°	6	2380	1·5	230°	− 65°
W.93	Trachyte	143°	6	12·5	1·9	187°	− 57°
W.141	Crinanite	128°	4	2370	0·9	185°	− 50°
N.6	Trachyte	68°	2	10·8	1·0	206°	− 62°
Lee Bay:—							
	Dolerite	Due E.	10	2540	3·8	181°	− 51°

(* Classified by Dr. Dollar.)

TABLE 2.

Age	Declination Ø	Dip I	Cone of Confidence half angle, α	Formation	
Devonian	N. 198° E.	− 2° UP	5°	Old Red Sandstone, Anglo Welsh Cuvette	(Creer, 1955, p. 73)
Triassic	213°	− 26°	7°	Keuper Marls	(Clegg, Almond, and Stubbs, 1954)
Eocene	194°	− 60°	3°	Antrim Basalts	(Hospers and Charlesworth, 1954)
Miocene?	171°	− 68°	4°	Mull lavas	(Dutt, 1955)
?	197°	− 59°	7°	Lundy dykes	

No conclusive result could be obtained with so few samples, which have a large scatter in directions of magnetization, though they appear to be magnetically stable. The mean direction for the granites has a declination of 175 degrees E. of N. and an upward dip of 9 degrees, with a 27-degree circle of confidence.

Conclusions

A comparison is made in Table 2 between the mean direction of magnetization of the Lundy dykes with those (irrespective of polarity) of British rocks of various ages. The mean direction for the Lundy dykes and the distribution of points about it on the stereogram, Text-fig. 3, closely resemble the result obtained by Hospers and Charlesworth (1954) for the Antrim lavas, which are undoubtedly Tertiary, and probably Eocene, in age. There is also reasonable agreement with the magnetization of the Mull lavas. The direction of magnetization of Carboniferous rocks in this country is still in doubt, but is likely to lie between the directions of Devonian and Triassic rocks, or to have still shallower dip. The magnetization of the Lundy dykes differs by at least 30 degrees from this, and is thus unlikely to be of Permo-Carboniferous age. Its close resemblance to that of the Antrim lavas is strong circumstantial evidence for their being contemporaneous, and supports the suggestion made by Hospers and Charlesworth that there may have been movement of the geographic poles relative to Britain since Eocene times.

The magnetization of the Lee Bay dyke indicates that it is a part of the Lundy swarm. The Lee Bay dyke and some dykes on Lundy are displaced by N.W.–S.E. faults to the same extent as the country rocks. This N.W.–S.E. fault system is regionally developed in South-West England. The Bovey Tracey and Petrockstow Clays appear to have accumulated in rift basins elongated along N.W.–S.E. lines, probably by faulting. The Bovey Clays are generally taken to be of Upper Oligocene age (Reid, 1913) and the faulting would appear to be penecontemporaneous. Hence the relation of the dykes to the faulting dates them as pre-Upper Oligocene.

The magnetization of the Lundy granites is not inconsistent with the idea of their being of Permo-Carboniferous age.

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REFERENCES

BLACKETT, P. M. S., 1952. A negative experiment relating to Magnetism and the Earth's Rotation. *Phil. Trans. Roy. Soc. A*, ccxlv, 309–370.

BRUCKSHAW, J. McG., and ROBERTSON, E. I., 1948. The measurement of magnetic properties of rocks. *Jour. Sci. Inst.*, xxv, 444–446.

CLEGG, J. A., ALMOND, MARY, and STUBBS, P. H., 1954. The remanent magnetization of some sedimentary rocks in Britain. *Phil. Mag.*, xlv, 583–598.

CREER, K. M., 1955. A preliminary palaeomagnetic survey of certain rocks in England and Wales. Ph.D. Dissertation, Univ. of Cambridge.

DOLLAR, A. T. J., 1941. The Lundy Complex: its petrology and tectonics. *Quart. Journ. Geol. Soc.*, xcvii, 39–77.

DUTT, S. K., 1955. The Mull lavas and their magnetism. Ph.D. Thesis, Univ. of London.

FISHER, R. A., 1953. Dispersion on a sphere. *Proc. Roy. Soc. A*, ccxvii, 295–305.

HOSPERS, J., and CHARLESWORTH, H. A. C., 1954. The natural permanent magnetization of the Lower Basalts of Northern Ireland. *Mon. Not. Roy. Astronom. Soc., Geophys. Suppl.*, vii, 32–43.

REID, C., 1913. (In) Geology of the country round Newton Abbot (Sheet 339). *Mem. Geol. Surv.*

VINCENZ, S. A., 1952. Remanent magnetization of some igneous rocks of Great Britain and its geophysical significance. Ph.D. Thesis, Univ. of London.

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The Taele Gravel near Thriplow, Cambridgeshire

By B. W. Sparks

(PLATE VII)

Abstract

The erratics, weathering and surface relief of the Taele gravel south of Thriplow point to its being immediately post-Gipping (Saale) in age. On the other hand, its molluscan fauna is of a type usually considered to be characteristic of cold conditions associated with the last glaciation. It is concluded that this fauna is characteristic of a certain type of local conditions and not of a definite period in the Pleistocene.

Introduction

RECENT working of a pit by the side of the A 505 road, one mile south of Thriplow (Nat. Grid Ref. 445447), has afforded the best section visible in recent years of the periglacial gravels mapped as Taele gravel by the Geological Survey (Text-fig. 1). It contains a significant molluscan fauna, the first to be recorded apart from early references to *Succinea*, *Pupa*, etc. (Penning and Jukes-Browne, 1881.)

Lithology and Erratics

Although in this type of gravel lithological variation is great, the general sequence visible in the 8-12 feet of section exposed is as follows:—

(4) A rusty, non-calcareous, weathered gravel forming an irregular surface layer, the average depth being about 2 feet and the deepest pipes extending to about 4 feet.

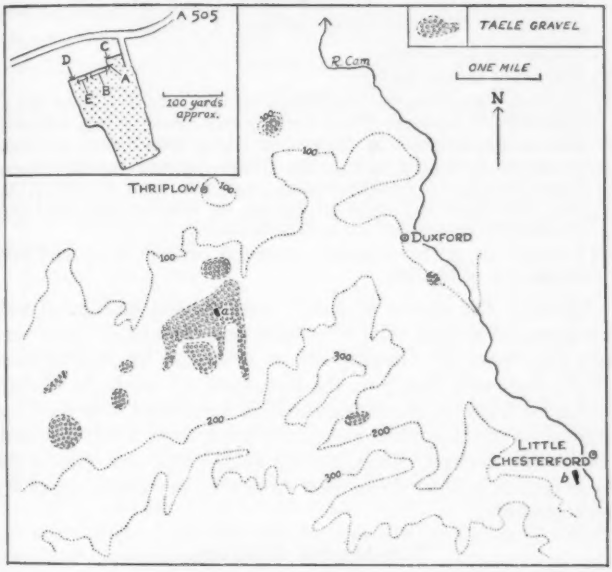
(3) A zone of marked frost-heaving (cryoturbation) affecting both of the layers below.

(2) Impersistent beds of unsorted fine material (mixed sand, silt, and clay), with a maximum thickness of about 4 feet, containing mollusca.

(1) A tumultuously-bedded gravel, principally composed of fresh-looking flints and with a high proportion of erratics. This extends as " flames " up through the bed above, where it is affected by frost action. These " flames " usually slope northwards.

The obvious provenance of this gravel is by solifluxion and associated action from the Chalk uplands two miles to the south, for it contains many unworn flint nodules and flint casts of *Holaster* and *Micraster* from Chalk zones outcropping south of the present position of the gravel. The boulder clay on these

Chalk uplands has recently been shown to possess a marked north–south orientation of its constituent stones and is probably of Gipping (Saale) age (West and Donner, 1956). As the Gipping boulder clay has a different set of erratics from the earlier Lowestoft drift (Baden-Powell, 1948), the erratics in the Taele gravel



TEXT-FIG. 1.—Distribution of Taele gravel near Thriplow, showing location of pit described (*a*) and Bordeaux pit (*b*). INSET.—Plan of pit (June, 1956) with positions of fossiliferous localities.

were examined to confirm that the gravel was derived from the south. They include:—

(*a*) Garnet-mica-schist, chlorite-schist, and quartzo-felspathic hornblende-schist. These are most likely to have come from the Highlands of Scotland.

(*b*) A well-graded coarse felspathic sandstone with pink felspars. ? Torridonian or sparagmite.

(*c*) Pink quartz-porphyry with phenocrysts of quartz, orthoclase and albite, greatly resembling in hand specimen and thin section rocks from Glen Etive and Glen Tilt. Dr. Agrell considers it more likely that this specimen was derived from the Highlands of Scotland than from the Southern Uplands.

(*d*) Pink biotite-granite.

(*e*) Rhomb-porphyry.

(*f*) Common grey and purple porphyrites greatly resembling rocks of Devonian or Carboniferous age from southern Scotland.

(*g*) Very common dolerites, including quartz-dolerites.

(*h*) Olivine-basalt. Three specimens were confirmed by thin sections.

(*i*) Carboniferous Limestone, Millstone Grit, and probably Coal Measures sandstones. The latter are not identifiable with certainty and may be from the Jurassic of north Yorkshire.

(*j*) Magnesian Limestone.

(*k*) Abundant Bunter pebbles.

(*l*) *Rhaxella* chert from the Yorkshire Corallian, and *Gryphaeas* of Lias and Oxford Clay type. The latter may be derived, as they are not as fresh as similar shells in the boulder clay at Barrington, which has abundant Jurassic erratics. Dr. Forbes informs me that he has found *Gryphaeas* bored by marine organisms, thus suggesting that they have been deposited in the sea by one ice sheet and later transported by another back on to the land.

(*m*) Ferruginous, gritty sandstone. Probably carstone from the Lower Greensand of Norfolk.

Although the source of many rocks cannot be located with certainty, the general suite of erratics accords much more closely with that from the Gipping till, as described by Baden-Powell (1948), than with that from the Lowestoft till, while the obvious derivation from the north is entirely in agreement with the stone orientation of the boulder clay to the south from which they were presumably derived. Thus, on the evidence of the erratics, the Taele gravels date at the earliest from the very beginning of the last interglacial.

Non-Marine Mollusca

Along the northern face of the pit at a depth of 5-7 feet mollusca were found in certain places. They are listed below under headings which refer to the inset diagram on Text-fig. 1.

	A	B	C	D	E
**Lymnaea truncatula* (Müller)	–	–	–	207	–
**Planorbis leucostoma* Millet	–	–	–	125	–
**Planorbis laevis* Alder	–	–	–	4	–
**Planorbis crista* (Linné)	–	–	–	1	–
Succinea arenaria (Bouchard-Chanteraux)	19	1	–	1,163	1
Succinea pfeifferi Rossmässler	4	4	–	175	–
Columella columella (Benz)	–	–	–	133	–
Pupilla muscorum (Linné)	–	309	11	1,110	104
Hygromia hispida (Linné)	–	–	–	1	–
Agriolimax? *agrestis* (Linné)	2	19	7	104	1
Agriolimax? *reticulatus* (Müller)	3	22	–	87	3
**Pisidium casertanum* (Poli)	–	–	–	23	–
**Pisidium obtusale* (Lamarck)	–	–	–	1	–
**Pisidium nitidum* Jenyns	–	–	–	14	–
	28	355	18	3,148	109

This fauna is peculiar in that the dry-loving species, *P. muscorum* is associated with the damp-loving genus, *Succinea*, the slug, *Agriolimax*, and freshwater species, marked with asterisks, capable of withstanding poor conditions, such as isolated swampy pools. The fauna is very like German *löss* faunas and contains not only many of the main species of that deposit, but also the same combination of dry-loving and damp-loving species.

But the material is not *löss*. Three samples of the material in which the mollusca occur were kindly analysed by Dr. R. M. S. Perrin. The material is so very calcareous, the three air-dried samples containing 35·15, 74·89, and 48·92% of calcium carbonate, that it was dispersed for analysis with 0·1% calgon, which does not destroy the calcium carbonate. Samples I and II are from the dry fauna locality, B, and sample III from D, where the richest fauna is found. The mechanical composition of the air-dried sediments is as follows:—

Particle Size (mm.)	I	II	III
Coarse sand (>0·2)	19·94	0·21	11·63
Fine sand (0·066–0·2)	21·36	16·61	12·70
Fine sand (0·02–0·066)	20·78	41·09	14·12
Silt (0·002–0·02)	18·63	24·72	33·87
Clay (<0·002)	16·27	13·65	25·20

None of the samples whether dispersed by calgon or by acid shows the characteristic sorting of *löss* or of wind-blown sand. Some degree of sorting is apparent in sample II, but the maximum is at a particle size (0·066 mm.), which is probably too coarse for *löss* and too fine for wind-blown sand moving by saltation. The high proportion of silt and clay in sample III is probably due to washing of finer particles into a hollow.

Thus, although the mollusca indicate a predominantly dry region (sections B, C and E) with damp hollows (sections A and especially D) and although they are extremely like a *löss* fauna, wind action, if it occurred, must have been confined to a slight local reworking of the finer constituents of the underlying gravel.

Most faunas of the Thriplow type are associated with the last glaciation, e.g. at Ponder's End; Barnwell Station, Cambridge; and Lord's Bridge, Cambridgeshire, but it is very unlikely that the Taele gravels are as recent as this. They form no surface feature and are now separated from the Chalk escarpment by a shallow valley, so that much more modification of relief has occurred since their deposition than in areas of Newer Drift. In addition the depth of the weathered horizon is, in the opinion of Dr. Perrin and the writer, too great to have been formed entirely since the last glaciation. As the weathered horizon thus seems to require an interglacial as well as the post-glacial period for its formation

and as it truncates the frost structures, ghosts of which can occasionally be seen in it, the frost heaving must date at the latest from soon after the Gipping glaciation. The erratics fix this as approximately the earliest period from which the gravels could date, so that the converging evidence strongly suggests that the gravels were laid down in a tundra period immediately after the Gipping glaciation.

This conclusion has an important bearing on the interpretation of Pleistocene molluscan faunas, for the presence of *Columella columella* (Plate VII, figs. *j-k*) or *Vertigo parcedentata* or both has usually been held to mean that the deposit containing them must be related in age to the last glaciation. This conclusion can no longer be held, as was suspected at Barrington where a deposit containing *V. parcedentata* appears to be considerably older than the last glaciation (Sparks, 1952). These faunas seem to indicate, therefore, a particular set of conditions and not a particular time in the Pleistocene. This may prove useful in the interpretation of other Pleistocene deposits, such as the Traveller's Rest gravels at Cambridge, which contain *C. columella* (Marr and King, 1928), but which are hardly likely to be of last glaciation age. Abroad, *C. columella* has been recorded from the Middle Terrace in Holland (Tesch, 1944), a deposit which predates the Eem transgression of the last interglacial, and from a bed dating from the end of the Saale glaciation at Ehringsdorf, Eastern Germany (Zeissler, 1956). Further afield, *C. columella* has recently been found at Horky in Central Bohemia in *löss*, which is considered to be of Riss I age at the latest (Ložek, 1956).

Relations with other Deposits

Finally, some consideration must be paid to the possible relations between these Taele gravels and other Pleistocene beds in the Cambridge district. The Taele gravels generally rest on a shelf or terrace at 100-140 feet O.D., which fringes the Chalk escarpment (Text-fig. 1), and were regarded by Osborne White as dissected remnants of a waste fan. Five miles away the Bordeaux Pit at Little Chesterford cuts through the end of what appears to be a waste fan (Sparks, 1955) and exposes a gravel similar in type and in degree of weathering to the Thriplow Taele gravels. Although the fauna in the Bordeaux Pit gravels is somewhat different from that in the Taele gravel, the upper level at that locality has a fauna dominated by the dry-loving *P. muscorum* and containing, in addition, damp-loving species in small numbers. In an earlier paper (Sparks, 1955), I recorded *Succinea oblonga* from the Bordeaux Pit, but a re-examination of the few adult

specimens from that locality suggests that they also are probably *arenaria*, though not quite typical in form (Plate VII).

Although anatomically quite distinct, the shells of these two species are separable only with great difficulty (Quick, 1933). *S. arenaria* tends to be less elongated, to have a deeper and less oblique suture, a blunter apex, a rounder mouth and more inflated whorls, even at the apex, than *S. oblonga*. But all these characters vary widely and whole populations rather than individual shells should be considered, for some specimens of *arenaria* (Plate VII, fig. *f*) approach specimens of *oblonga* extremely closely (Plate VII, fig. *h*). These slight differences are illustrated by photographs of Pleistocene specimens (Plate VII), for it is very desirable to attempt to differentiate between the two, as they prefer different environments. *S. oblonga* is more characteristic of mud at the side of ditches (Boycott, 1934) and marshes, while *S. arenaria* prefers damp depressions between sand dunes as at Braunton Burrows, Devon (Quick, 1933). These are precisely the the conditions envisaged for *S. arenaria* both at the Bordeaux Pit and at Thriplow, though not at Barrington, where it has also been found (Sparks, 1952).

There are old records of mollusca from gravels at Pampisford and Little Wilbraham between Cambridge and the Chalk escarpment (Penning and Jukes-Browne, 1881), but only genera are given. The sections are no longer open, and the specimens appear to have been lost as they cannot be traced either in the Sedgwick Museum or in the Geological Survey collections. They seem to have had small faunas and it would be interesting to discover whether the Chalk escarpment is fringed by solifluxion gravels of immediately post-Gipping age, but the only localities where the gravels can be shown to be of this age without much doubt are the Bordeaux Pit and the patch of Taele gravels described in this paper.

I am greatly indebted to Drs. R. W. Hey, S. O. Agrell, and C. L. Forbes for assistance with the erratics; to Dr. R. M. S. Perrin for the sedimentary analyses; to Mr. Hugh Watson for examining the specimens of *Succinea*; to Mr. R. V. Melville for searching for specimens in the Geological Survey collections and to Dr. R. A. Auty for the translation of a Czech paper.

REFERENCES

Baden-Powell, D. F. W., 1948. The chalky boulder clays of Norfolk and Suffolk. *Geol. Mag.*, lxxxv, 279–96.

Boycott, A. E., 1934. The habitats of land mollusca in Britain. *Journ. Ecol.*, xxii, 1–38.

Marr, J. E., and King, W. B. R., 1928. Notes on the Pleistocene deposits of the Cambridge district. *Geol. Mag.*, lxv, 307–12.

LOŽEK, V., 1956. *Vertigo pseudosubstriata* Ložek v Pleistocénu v Horkách nad Jizerou. *Anthropozoikum*, 5 (1955), 363–4. Prague.

PENNING, W. H., and JUKES-BROWNE, A. J., 1881. The geology of the neighbourhood of Cambridge. *Mem. Geol. Surv.*

QUICK, H. E., 1933. The anatomy of British Succineae. *Proc. Malac. Soc.*, xx, 295–318.

SPARKS, B. W., 1952. Notes on some Pleistocene sections at Barrington, Cambridgeshire. *Geol. Mag.*, lxxxix, 163–74.

—— 1955. Notes on four Quaternary deposits in the Cambridge region. *Journ. Conch.*, xxiv, 47–53.

TESCH, P., 1944. Nieuwe lijst der kwartaire land- en zoetwatermollusken in Nederland. *Mededeelingen van's Rijks Geologischen Dienst*, Serie A, No. 10., 's-Gravenhage.

WEST, R. G., and DONNER, J. J., 1956. The glaciations of East Anglia and the East Midlands. *Quart. Journ. Geol. Soc.*, cxii, 69–92.

WHITE, H. J. O., 1932. The geology of the country near Saffron Walden. *Mem. Geol. Surv.*

ZEISSLER, H., 1956. *Pisidium vincentianum* im Ehringsdorfer Pleistozän. *Archiv für Molluskenkunde*, lxxxv, 197–8.

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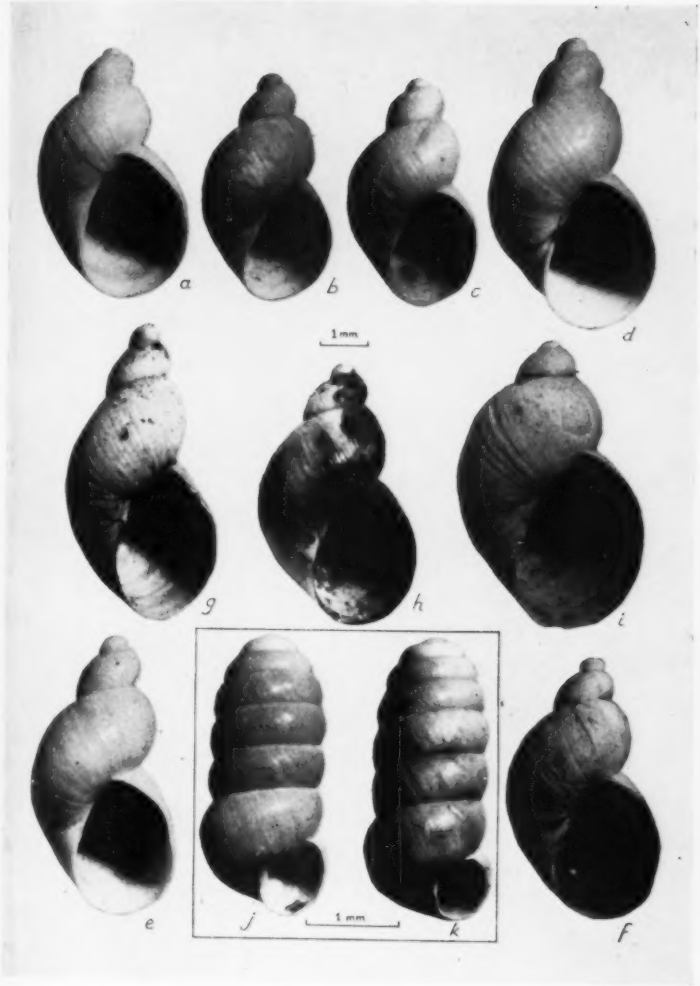
DESCRIPTION OF PLATE VII

FIG. *a-b*	*Succinea arenaria* (Bouchard-Chanteraux).	Eastwood's pit, Barrington.
c-e	" " " "	Taele gravel, near Thriplow.
f	" " " "	Bordeaux pit, Little Chesterford.
g	*Succinea oblonga* Draparnaud	Forest bed, West Runton.
h-i	" " "	Bobbitshole, Ipswich.
i-k	*Columella columella* (Benz)	Taele gravel, near Thriplow.



SUCCINEA AND *COLUMELLA*.

Evolutionary Rates of Brachiopods

By Alwyn Williams

Abstract

A survey of brachiopod genera along lines currently adopted by students of evolution suggests that for this phylum at least the raw data can change significantly from year to year dependent upon systematic opinion and regional influences, and that even if such data are accepted as reasonable reflections of brachiopod evolution they lead to conclusions different from those published for other phyla.

DR. G. G. SIMPSON'S latest book (1953) has brought to an early climax many attempts to provide evolutionary aspects of palaeontology with a quantitative foundation. This trend, largely stimulated by Simpson's novel techniques (for example, 1944, 1952), has become quite fashionable. An ever-increasing number of papers dealing with the development of fossil groups contain a host of graphical and numerical devices designed to provide a sober tone of objectivity to the accompanying text. On the whole they appear to be extremely useful, but there is a real danger that the student will lose sight of the tenuous and arbitrary nature of most of the data used in the compilation of such charts, for there is always a tendency to accept numbers as the only worthwhile facts in papers of this kind. The risk of being misled is especially true in the calculation of taxonomic rates, those estimates which are intended to give us comparative and absolute time measures of the proliferation, survival, and extinction of various groups within the systematic hierarchy.

In a sub-chapter entitled " Group Rates and Survivorship ", Simpson (1953, p. 38 *et seq.*) discusses generic longevity among pelecypods and carnivores, and concludes that " in terms of durations of genera carnivores have evolved faster, on an average, than pelecypods. That they may have evolved ten times as fast represents a probable upper limit for the difference." In the course of his calculations he expatiates on possible sources of error in his estimates, but with such a confidence in their inability to affect his conclusions that one is immediately tempted to test his generalizations, doubtless a challenge that Simpson intended.

The first line of inquiry concerned the effect that the publication of new genera, year by year, would have on the charts. Simpson clearly believes that for the pelecypods at least " it is improbable that more recent data will make any real difference in orders of magnitude of rates, in general shapes of curves based on the data, or in such conclusions as are here drawn " (p. 39). Applied to

the brachipods, this opinion suggests that by 1894, when the first "modern" comprehensive survey of brachiopods was published by Hall and Clarke, faunal sampling was sufficiently adequate and systematic procedure mature enough to anticipate all future research.

Fortunately comparative historical surveys showing the development of brachiopod systematics are easily accessible. Apart from Hall and Clarke's monographs (1891, 1894) another exhaustive compilation was prepared by Schuchert and Le Vene in 1929, and the present time furnishes yet a third grade of data.

TABLE 1

Systemic distributions of brachiopod genera according to first known appearance (*a*) and last known occurrence (*b*). The left, middle and right columns in both groups represent data for 1894, 1929, and 1956 respectively.

	a			*b*		
Rec.	15	17	25	29	63	71
Tert.	5	39	64	1	8	32
Cret.	12	32	44	14	33	45
Jur.	31	119	143	25	111	136
Trias.	31	44	53	30	40	49
Perm.	5	44	119	15	83	162
Carb.	31	96	167	46	90	165
Dev.	66	110	243	72	113	247
Sil.	44	71	123	37	64	114
Ord.	61	107	316	38	81	284
Cam.	22	52	80	16	45	72
	323	731	1,377	323	731	1,377

These are presented in Table I. A chi-square test confirms the impression given by a scan of the figures. namely that the differences between all three, as well as between the 1929-1956 sets of figures are highly significant ($p < .001$), and when rates of generic proliferation per million years are calculated, in the manner adopted by Simpson and Newell (1952) the effects of these differences are immediately seen. Between 1894 and 1929 the peak of brachiopod evolution, expressed in this way, moved from the Silurian to the Jurassic, and has lately retreated to the Devonian, with the Ordovician record providing a strong secondary maximum. The post-Cambrian—pre-Cretaceous minimum is more staid. It has only moved from the Permian to the Trias and has remained there since the turn of the century.

The reasons for these migrations are not hard to find. Up to 1894 the most prolific creators of genera were James Hall and

his associates, and their particular hunting ground consisted of the classical sections of New York State and adjacent territories with their magnificent and richly fossiliferous exposures of Upper Ordovician, Silurian, and Devonian age. It may even be true to say that Hall's knowledge of the Mesozoic was slight, and the coincidence of the limits of his experience with the Silurian maximum in brachiopod genera suggests that regional geology, and not scientific impartiality, played a very important part in determining the pattern of generic rates. This influence also accounts for the Permian minimum (only Waagen's study of the Salt Range was of any consequence up to that time) and the Triassic and Jurassic recoveries. The former was due almost entirely to Bittner's prolonged and intensive researches into Austrian faunas of that age, and the latter, of course, was a measure of European familiarity with classical and accessible sections at least as rich as the Lower Palaeozoic ones of North America. It may be argued that if regional geology did play so important a part in brachiopod taxonomy, the Jurassics, which at that time were much better known than the American Palaeozoics, should have provided a maximum. Two factors tended to confound this expectation: first, the undeniable fact that the brachiopods were in decline during Mesozoic times, and second, the dominating influence of Thomas Davidson, Hall's counterpart in Europe, who, even by the standards of those days, was an extremely conservative systematist. Indeed, the effect of Davidson's approach to classification is well shown by the decided swing of the maximum between 1894 and 1929, for in the early part of this century Buckman succeeded Davidson as Britain's brachiopod specialist, and his radical systematics resulted in a markedly disparate Jurassic peak. Had Buckman given his undivided attention to brachiopod-bearing strata of another system, the maximum would have migrated with his wandering fancy.

Since 1929 the vortex of systematic activity has shifted back to Lower and Middle Palaeozoic faunas, largely through the immense labours of Dr. G. A. Cooper, and as a result of studies by Dr. A. A. Öpik and others, maximum proliferation has returned to that part of the geological column, although not in re-affirmation of the relationships suggested by Hall and Clarke's survey, because their Silurian maximum has now become a marked depression between the Ordovician and Devonian maxima.

The vacillations of maxima and minima of brachiopod generic rates, then, are attributable not only to the subjective nature of taxonomic assessment, but also to regional determinism, and the differences are significant enough to suggest that generalizations

about fluctuations in evolutionary rates invite the hazard of gross deception. For example, most palaeontologists talk of a Permo-Triassic " life-crisis ", and the present depressed rate of brachiopod evolution during Triassic times seems to substantiate this assumption. But no comprehensive revision of Triassic faunas has taken place since Bittner's time, and many students of the group, knowing his work, feel confident that the Triassic faunas will ultimately prove far more varied than we are led to believe, and probably more prolific systematically than those of the succeeding Jurassic, whose peak is, in any event, somewhat artificial (Cooper and Williams, 1952, p. 330). After all, in the days of Hall and Clarke, Permian brachiopods were represented as being at a low ebb in evolutionary activity, while to-day it appears that their rate of development was quite high, and it is to be expected that when Cooper has completed his investigations of the Glass Mountain faunas it will reach a peak, vying temporarily at least with the Lower Palaeozoic ones.

The issues involved are frequently obscured by blaming all of the uncertainties inherent in data of this kind on taxonomic splitting—that is, the erection of new genera by restricting the limits of already established ones. This effect of splitting appears to hold for the data presented here. 140 new genera, described in six monographic studies of brachiopods,[1] were allocated to one of two groups depending on whether they were founded on or included previously described species, or whether they were based on new species, unrecorded anywhere else at that time. 92 genera were splits, 48 represented discoveries: an approximate proportion of two to one. The figures of Table 1 were then re-adjusted by this factor, and a chi-square test showed that the differences attributable to new discoveries were not significant ($\cdot 2 > p > \cdot 1$). In other words, when due allowance is made for variability within the data, new discoveries have not materially altered the pattern of distribution since 1894, and any differences in maxima and minima that appear in graphs are not significant. But it is unreasonable to assume that all splits are unwarranted, particularly when the basic data are so uneven in their systematic merits. Students of the phylum will appreciate this opinion when it is pointed out that in 1894 all plectambonitaceids were referred to only two genera, *Leptella* and *Plectambonites*, though the dinorthid *Plaesiomys* had already been separated from *Dinorthis*, s.s., and the atrypid *Karpinskia* from *Atrypa*, etc.; and if even as much as 80% of the splits are unnecessary, the residue of " meri-

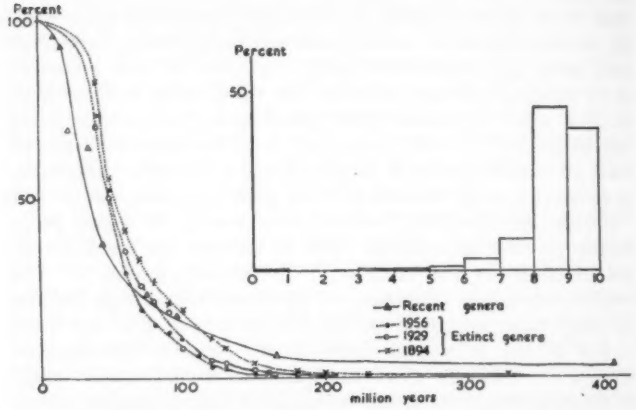
[1] They were: Cloud (1942), Cooper (1956), Kozlowski (1929), Schuchert and Cooper (1932), Stehli (1954) and Thomson (1926).

torious" revision coupled with discoveries are sufficient to have altered the data significantly (at the 1% level) within the last fifty years. Nor is there any reason to assume that brachiopod taxonomy has now approached its climax, and that present-day figures may be used with impunity. Improved techniques and more patient collecting promise a great deal more. For example, Cooper's large-scale etching of the supposedly well-sampled Middle Ordovician rocks of Appalachia, carried out over the last fifteen years, was responsible for his discovering no fewer than 39 new genera. Many of these have turned up, again without previous record, in entirely new fossil localities in the Girvan area, which has been so intensively exploited for over a century as to produce enough material for thirty-seven monographs. In all, it seems at present quite permissible, and in some cases even preferable, to trust charts, etc., in which adjustment can be made to include personal judgment and systematic experience, as demonstrated by Westoll for lung fishes (see Simpson, p. 22).

Having assembled this body of data, suspect as it may be, it became possible to calculate rates of survival for brachiopods, and to construct the so-called "survivorship graphs". The results obtained by Simpson are extremely interesting, because the suggestion that carnivores evolved at a rate up to ten times as fast as the pelecypods immediately conjures up contrasts between the media in which these animals lived and their effect on selection pressures. Is the evolution of their respective genetic systems similar in tempo but masked in the case of the pelecypods by the more uniform conditions of a water environment? Or were there very profound differences in their inherent variability?

The survivorship curves for the three sets of data are given in Text-fig. 1, and are obviously very similar in form. They also show that systematic activity over the years has resulted, as one would anticipate (Simpson, p. 41), in a decrease in the estimates of mean longevity. The means for the data known in 1894, 1929, and 1956 are 64, 56, and 53 million years respectively, a range sufficiently small to suggest that the carnivores evolved about seven times as fast as the brachiopods. This proportion is strongly reminiscent of Simpson's estimates for pelecypods. But in terms of comparative evolution such conclusions are misleading, for Simpson has used data for one group of animals with ranges estimated to within a sub-series during the climax of their radiation (a feature of mammalian evolution which he himself has stressed on many occasions) and compared them with calculations for another group of animals with ranges to the nearest system

over their entire geological record, irrespective of their evolutionary stability. It seems, then, more logical to compare the Tertiary carnivores not with the entire brachiopod record, but with a climax within that record. For this purpose the Ordovician was chosen as the most appropriate period, following as it does some hundred million years of earlier evolution, a similar span to that undergone by the carnivores during Mesozoic times. The data were treated in exactly the same way as were Simpson's;



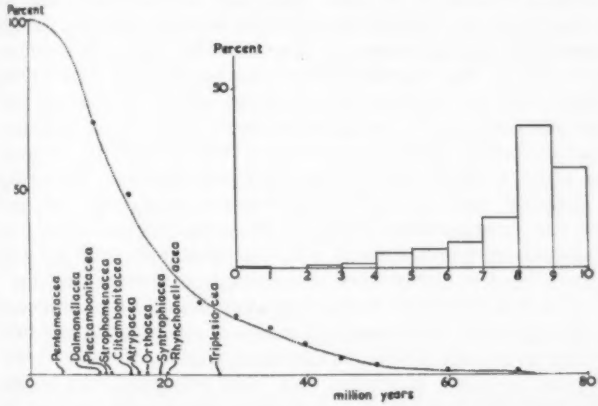
TEXT-FIG. 1.—Survivorship curves for extinct brachiopod genera according to data for 1894, 1929, and 1956, and for recent genera with a geological record. The inset histogram is a conversion of the 1956 curve, assuming that evolutionary rates are reciprocals of longevity so that each decile of the abscissa represents a degree of intensity of evolution.

all genera originating in Cambrian times or existing after the close of the Ordovician were omitted, leaving a residue of 231 genera. The Tremadocian has been added to the system to facilitate correlation with American and Baltic successions, and the duration of the record was estimated rather generously as 90 million years, which conveniently allowed the allocation of 15 million years for each series.

The results are given in Text-fig. 2, and what a remarkable difference there is! The average duration of the brachiopod genus has now dropped to 16 million years, and the means for the eight most important superfamilies, excluding the triplesiaceids (two genera) and the pentameraceids (three genera), range from 10·5 to 20·5 million. In the face of such conflicting results it would

be foolish to draw any conclusions from the figures given above. The most we can say is that at some time in brachiopod evolution the estimated rates of generic proliferation and hence possibly speciation may have been comparable with those postulated for the Tertiary carnivores.

Comparative analyses of survivorship curves have enabled Simpson to propound the concepts of horotely, bradytely, and tachytely, which may be defined briefly as follows. If rates of evolution are reciprocals of longevity, then survivorship curves



TEXT-FIG. 2.—A survivorship curve for 231 Tremadocian and Ordovician articulate genera together with the mean generic longevity for every super-family recorded during those times and an inset histogram showing the distribution of evolutionary rates.

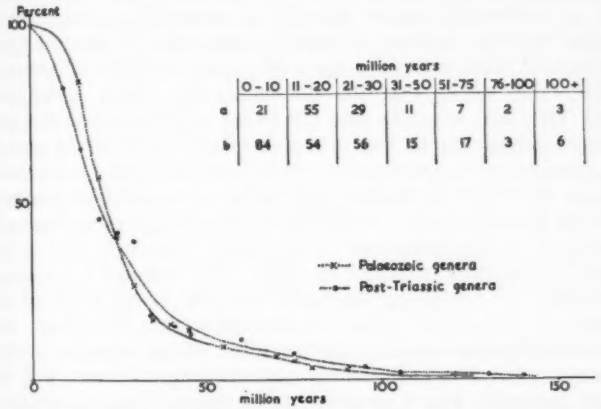
provide a means of arriving at comparative estimates of degrees of intensity of evolution by using a quantile division of the abscissa in place of absolute time (e.g. Text-figs. 1 and 2). Histograms built up in this way for pelecypods, carnivores, and diatoms (Simpson, pp. 316-7) and also for brachiopods have a number of characteristics in common, the most important of which are that in each group cited a clear majority of stocks fall within one grade of the evolutionary scale, and that this mode is near the top of the scale, so that only a smaller number of residual stocks had a higher evolutionary rate while the rest, possibly numerically superior to the mode, tail off into the lower, slower, evolutionary grades. This markedly skewed distribution may

well be characteristic of phyla generally, and Simpson has proposed that the term *horotely* be used to describe such a pattern. He further notes that some groups are remarkable for extremely slow rates of evolution, with a persistence, for we are working with the same premise, viz., evolutionary rates are inversely proportional to longevity, far in excess of their expectation as calculated from survivorship tables of horotely. This low-rate excess has been described by him as *bradytely*, and the other extreme, the very high rates of evolution, as *tachytely*.

How important these conceptions are to our understanding of evolution remains to be seen. Bradytely and tachytely may be no more than two special aspects of the horotelic pattern, though Simpson, in his discussion of their possible inter-relationships, denies this. But calculations of the brachiopod data (1956) suggest that we are not yet at a stage where conclusions and generalizations can be drawn, particularly with regard to bradytelic distribution (tachytely is no more than an opinion, although one which is firmly held by most palaeontologists). According to Simpson, there is a difference between bradytelic rates and even very slow horotelic rates, and he seems inclined to see it as " quantitative and statistical with intergradation, and yet with mean differences and possible discontinuity of average outcome " (p. 327). It is difficult to understand what this statistical difference is, though I take it to mean the excess of stock persistence over expectancy as calculated from survivorship tables of extinct forms. Simpson has put it in another way. The pelecypod data he uses show that there are genera living to-day which have endured far longer than any extinct one. No one need doubt this observation, for even if his pelecypod genera are too broadly drawn, examples can be quoted from other phyla. The classic example is, of course, the brachiopod *Lingula*, which appears to have undergone no systematically significant change since Ordovician times. Text-figure 1 shows the effect of long-lived stocks, *Lingula* and *Crania*, on the tail of a cumulative graph of the 47 recent genera known to have a geological record. Comparison with other cumulative curves shown on the graph is not particularly instructive, because of the great disparity in the proportions of inarticulate to articulate genera from one set of data to another. For unfortunately very little is known about either the morphology or the range of inarticulate brachiopods, and it is at present impossible to say whether long-lived genera were so common in that sub-phylum as to constitute a reasonable tail to a subdued horotelic pattern, or whether they are bradytelic in Simpson's sense of the word. But if bradytely is an integral part of the evolutionary process,

then it should also be apparent in the calcareous-shelled brachiopods.

Terebratulina, and possibly *Argyrotheca*,[1] are the recent articulate brachiopods with the longest geological records. They have a range reputed to be equivalent to about 150 million years. Off-hand, there are four Palaeozoic genera—*Leptaena*, *Chonetes*, *Rhipidomella*, and *Schizophoria*—with a comparable range, so that on this diagnosis alone, there is no surviving articulate



TEXT-FIG. 3.—Survivorship curves for rhynchonelloids and terebratuloids at stated times in their geological history. The inset table shows the distribution of genera according to age groups (in millions of years), the upper column (*a*) containing Palaeozoic genera and the lower (*b*) post-Triassic ones.

brachiopod which may be described as bradytelic. The validity of this comparison may be questioned on the grounds that the Palaeozoic genera given above are bradytelic members of extinct orders, whereas *Terebratulina*, *Argyrotheca*, or for that matter any recent brachiopod, may be a bradytelic stock *in statu nascendi*. There is no morphological prescription for identifying such long-range stocks. Yet, as Simpson has recorded (p. 325), with the passage of time an increasing residue of persistent genera should provide sufficient excess over expectancy to alter survivorship curves significantly. With this aim Jurassic to recent rhynchonelloids and terebratuloids have been compared with their Palaeozoic ancestors (Text-fig. 3). Apart from the fact that

[1] I am indebted to Mr. Graham Elliott, of the Iraq Petroleum Company, for his expert opinion on the geological ranges of some recent brachiopods.

Terebratulina and *Argyrotheca* have apparently persisted for a longer period than any Palaeozoic rhynchonelloid or terebratuloid (though *Stenoscisma* is within ten million years of them) there is no conclusive evidence to suggest that there is any significant bradytelic accumulation in the younger stocks. On the contrary, there is a startling contrast between the two sets of data in that the mean longevity of the post-Triassic genera is slightly less than that for their ancestors (24·4 and 24·7 million years respectively). The inset table of Text-fig. 3 gives a better idea of the composition of the various age groups than do the cumulative curves, which suffer from the handicap of having a continuum of absolute time calculated in disjunct proportions of systems and parts of systems. This table shows that the differences are highly significant ($p > \cdot 001$) due, as can be seen, not to any great discrepancy in the longer-ranging stocks, but to a post-Triassic mode of 84 genera supposedly existing for less than 10 million years, and a Palaeozoic mode of 55 genera calculated as having a longevity of between 11 and 20 million years. Undoubtedly the estimate of the younger group is greatly influenced by Buckman's excessive systematic zeal and his exact estimates of range. This bias can be partially remedied by combining the figures of cells 1 and 2, in which event the differences are no longer significant and, indeed, the two distributions are remarkably similar. What objective reality these comparisons have is impossible to judge : it may well be that systematic bias is so strong as to obscure essential dissimilarities, but it seems reasonable to accept the present data with as much assurance as Simpson has for his own estimates, and in the light of so many contradictions a number of his generalizations appear to be premature for the brachiopods at least.

REFERENCES

Cloud, P. E., 1942. Terebratuloid Brachiopoda of the Silurian and Devonian. *Geol. Soc. Amer.*, Spec. papers, 38.

Cooper, G. A., and Williams, A., 1952. Significance of the stratigraphic distribution of brachiopods. *Journ. Paleont.* xxvi, 326–337.

Cooper, G. A., 1956. Chazyan and related brachiopods. *Smithsonian Inst.* 127, 2 pts.

Hall, J., and Clarke, J. M., 1891 and 1894. *An introduction to the study of the Brachiopoda.* I and II, Albany, N.Y.

Kozlowski, R., 1929. Les brachiopodes gothlandiens de la Podolie polonaise. *Palaeont. polonica.* Warsaw.

Newell, N. D., 1952. Periodicity in invertebrate evolution. *Journ. Palaeont.*, xxvi, 371–385.

Schuchert, C., and Cooper, G. A., 1932. Brachiopod genera of the suborders Orthoidea and Pentameroidea. *Mem. Peabody Mus. Nat. Hist.* IV.

SCHUCHERT, C., and LE VENE, C. M., 1929. Brachiopoda. *Fossilium Catalogus* 42. Berlin.

SIMPSON, G. G., 1944. *Tempo and mode in evolution.* Columbia University Press.

—— 1952. Periodicity in vertebrate evolution. *Journ. Palaeont.*, xxvi, 395–370.

—— 1953. *The major features of evolution.* Columbia University Press.

STEHLI, F. G., 1954. Lower Leonardian Brachiopoda of the Sierra Diablo. *Bull. Amer. Mus. Nat. Hist.*, 105, 263–357.

THOMSON, J. A., 1927. Brachiopod morphology and genera (Recent and Tertiary). *N.Z. Board of Sci. and Art*, 7.

THE QUEEN'S UNIVERSITY,
BELFAST.

A Temperate Bed of the last Inter-glacial Period at Northfleet, Kent

By J. P. T. Burchell

Abstract

The molluscan fauna of the deposits infilling the Ebbsfleet Channel is listed; it comprises forty-one species and demonstrates the existence of an interglacial phase.

As a result of continuous support received from the Management of the Associated Portland Cement Manufacturers Co., Ltd., and the Trustees of the Percy Sladen Memorial Fund, I have been enabled, over the past twenty-five years or so, to conduct extensive investigation of the deposits comprising the infilling of the Ebbsfleet Channel, a channel cut through the Main Coombe Rock of the district. From time to time short statements have appeared as the work has proceeded (Burchell, 1935, 1936*a*, *b*).

The research is now completed and though it would be beyond the scope of this short note to supply even an abbreviated summary of the results obtained, it is thought desirable to put on record the highly significant molluscan sequence which occurs in the upper part of the section and which demonstrates the occurrence of a truly inter-glacial phase.

The shells comprising this assemblage number forty-one species and are in marked contrast to the total of six species encountered in the deposits forming the lower part of the geological sequence. Further, the presence of *Corbicula fluminalis* and *Discus rotundatus*, coupled with the complete absence of any arctic species in the deposit, is additional evidence of amelioration in climatic conditions. This Temperate Bed finds its counterpart in the *Corbicula* horizon of the Crayford district (Burchell, 1954).

Suffice it to say now that the upper part of the Middle Loam (a loessic deposit to be equated with the Older Loess)—overlying a Coombe Rock and characterized by the shells of *Pupilla muscorum* and *Vallonia costata*—passes up into a weathered land-surface upon which Micoquian Man made the artifacts which are found in the overlying Upper Loam or Temperate Bed. This bed, a greyish-brown loam containing a few pebbles scattered throughout, has yielded the undermentioned molluscan fauna of temperate facies:—

Land types:

Agriolimax sp.	8
Arianta arbustorum Linn.	frgts.
Arion sp.—small	sc.
Azeca goodalli Fér.	5
Carychium minimum Müll.	30
,, *tridentatum* Risso.	22

Clausilia bidentata Ström.	10
Coecilioides acicula Müll.	2
Cochlicopa lubrica Müll.	6
Discus rotundatus Müll.	38
Helix nemoralis Linn.	frgts.
Hygromia hispida Linn.	31
Limax sp.	2
Oxychilus cellarius Müll.	8
Punctum pygmaeum Drap.	2
Pupilla muscorum Linn.	81
Retinella nitidula Drap.	15
„ *pura* Ald.	6
„ *radiatula* Ald.	1
Vallonia costata Müll.	19
„ *excentrica* Sterk.	19
„ *pulchella* Müll.	20
Vertigo pygmaea Drap.	2
Vitrea contracta West.	4
„ *crystallina* Müll.	1

Marsh and freshwater types :

Ancylus fluviatilis Müll.	1
Bithynia tentaculata Linn.	9 opercula
Corbicula fluminalis Müll.	frgts.
Limnaea palustris Müll.	2
„ *peregra* Müll.	120
„ *truncatula* Müll.	65
Pisidium casertanum Poli	12
„ *henslowanum* Shepp.	9
„ *personatum* Malm.	11
Planorbis crista Linn.	2
„ *laevis* Ald.	3
„ *planorbis* Linn.	23
Succinea pfeifferi Rossm.	31
Valvata cristata Müll.	10
„ *piscinalis* Müll.	4
Zonitoides nitidus Müll.	8

In addition, the bones and/or teeth of *Elephas primigenius*, *Rhinoceros* sp., *Cervus megaceros*, and *Equus caballus* have been recovered from the deposit in question.

In its uppermost part the Middle Loam or Temperate Bed in places passes up into a thin deposit of highly calcareous loam which contains the following restricted molluscan fauna—thus anticipating the formation of the immediately overlying Coombe Rock and its accompanying return of glacial conditions:—

Land types :

Agriolimax sp.	2
Pupilla muscorum Linn.	57
Vallonia excentrica Sterk.	1
„ *pulchella* Müll.	1

Marsh and freshwater types :

Limnaea peregra Müll.	3
„ *truncatula* Müll.	3
Succinea pfeifferi Rossm.	10

In due course it is hoped to prepare a detailed and illustrated account of the Ebbsfleet Channel and its contents.

I express my gratitude to my former colleague, the late Mr. A. G. Davis, who has devoted much time to the identification of the shells which, together with the mammalian remains, are housed in the British Museum (Natural History), London, S.W. 7.

REFERENCES

BURCHELL, J. P. T., 1935. Evidence of a Further Glacial Episode within the Valley of the Lower Thames. *Geol. Mag.*, lxxii, 90–1.

—— 1936*a*. Evidence of a Late Glacial Episode within the Valley of the Lower Thames. *Geol. Mag.*, lxxiii, 91–2.

—— 1936*b*. A Final Note on the Ebbsfleet Channel Series. *Geol. Mag.*, lxxiii, 550–4.

—— 1954. Loessic Deposits in the Fifty-foot Terrace post-dating the Main Coombe Rock of Baker's Hole, Northfleet, Kent. *Proc. Geol. Assoc.*, lxv, 256–261.

FAWKE COMMON,
SEVENOAKS,
KENT.

A Palaeontological Link between the Midgeholme Outlier, Cumberland, and the Northumberland and Durham Coalfield

By W. Hopkins and G. M. Bennison

Abstract

A prominent shell bed from the Middle Coal Measures of the Midgeholme Coalfield, Cumberland, is here recorded for the first time. The fauna, consisting of non-marine lamellibranchs is listed and briefly described. It establishes that the horizon of the Cannel Seam at which the shell bed occurs is within the *C. pseudorobusta* Sub-zone of the upper part of the *C. communis* Zone.

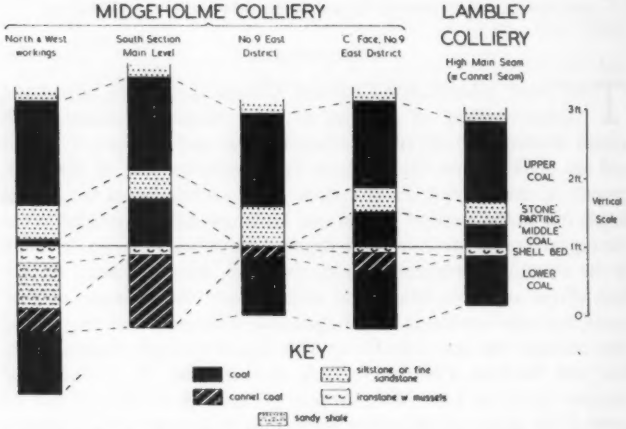
Introduction

THE small Midgeholme Coalfield, Cumberland, is the largest and most westerly of a series of Coal Measures outliers which extend westwards from the Northumberland and Durham Coalfield and are preserved on the northern or downthrow side of the components of the Stublick Fault system. Our knowledge of the field is largely due to the work of Trotter and Hollingworth as recorded in the Geological Survey Memoir of the Brampton district (1932, pp. 98–112). In the absence of palaeontological evidence, these workers, on the basis of the available lithological evidence and the sequence of coal seams, not only correlated the Midgeholme succession with that of the other outliers, but also linked it up with that of the main Northumberland and Durham Coalfield. They showed that the Midgeholme sequence up to the Low Main horizon is made up of 200–270 feet of Lower Coal Measures (formerly mapped as Millstone Grit), which in turn are overlain by 460 feet of Middle Coal Measures. In Durham the Brockwell Seam, which they considered to be the equivalent of the Midgeholme Low Main, is the boundary between the Middle and Lower or Gannister Groups.

Faunal Divisions

Owing to the paucity of relevant fossils, Trotter and Hollingworth were unable to divide the Midgeholme sequence into floral or faunal divisions. Indeed, they record only one fossil locality and that from a dump where a water level near the bridge at Midgeholme passed through a mussel band rich in ostracods and *Spirorbis* overlying the Craignook Seam (op. cit., p. 109). They correlated this band with the shell bed above the Harvey Seam of Durham and its equivalent the Beaumont Seam of Northumberland (op. cit., p. 100). This latter shell bed is a prominent mussel-ostracod bed with *Spirorbis* and is the most distinctive and persistent shell bed in Northumberland and Durham

(Hopkins, 1927, pp. 231–2). It occurs in the lower half of the *A. modiolaris* Zone (Hopkins, 1929, pp. 131–2 ; 1930, pp. 104–5) and was subsequently named the Hopkins Shell Bed by the Geological Survey (Eastwood, 1935, p. 54). The Craignook horizon at Midgeholme, therefore, should also lie within the *A. modiolaris* Zone. The presence of the underlying *C. communis* Zone at Midgeholme has hitherto only been inferred from a correlation of the Midgeholme seams with those in Durham which on palaeontological evidence are known to occur in this zone. Recently, however, we have been particularly fortunate in finding a conspicuous shell bed near the base of the



TEXT-FIG. 1.—Detailed sections of the Cannel Seam in the Midgeholme Coalfield.

Middle Coal Measures at two localities in the Midgeholme field. The faunal assemblage is characteristic of the upper part of the *C. communis* Zone. The occurrence of this shell bed is rather unusual as it occurs in a band in a coal seam and not in the roof strata. It was found in an ironstone parting in the Cannel Seam at Midgeholme and in the equivalent High Main Coal at Lambley one mile to the east. The Cannel Seam is approximately 220 feet below the Craignook Seam.

LITHOLOGY OF THE CANNEL SEAM SHELL BED

Practically everywhere in the Midgeholme and Lambley Colliery workings, the Cannel = High Main Coal is characterized by two partings which split the seam into three leaves (Text-fig. 1). The lower parting consists only of a few inches of ironstone except in the northern and western Midgeholme workings and in the old Midgeholme King

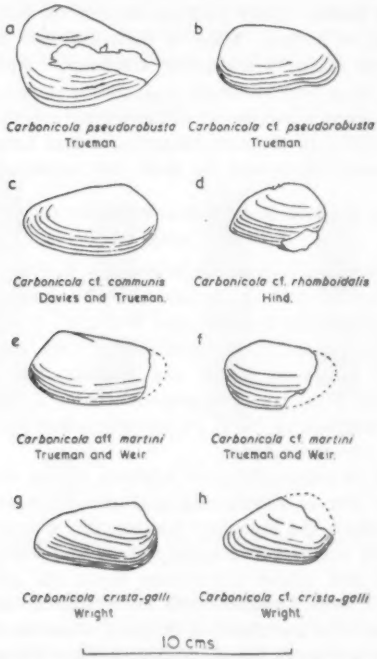
Pit workings where as much as 1 foot of sandy shale may be present. The upper parting consisting of hard fine-grained sandstone occurs between the " middle coal " and the upper leaf and is known locally as the " stone parting ". This parting all but merges into the lower parting in the north and west workings at Midgeholme Colliery. The shells always occur in the ironstone parting below the " middle coal ", and are most numerous where the ironstone has its maximum thickness of 3 inches. Coaly partings occur in the ironstone and it is full of nodules of pyrites. Many of the solid shells are replaced by pyrites ; others occur in a crushed condition. Although difficult to extract, we have been fortunate in obtaining some solid specimens. The shells are most numerous at Midgeholme Colliery. As the ironstone is followed into the east Midgeholme and Lambley workings it becomes much thinner and the shells less numerous.

Fauna of the Cannel Seam Shell Bed and its Stratigraphical Significance

The shells identified include the following : *Carbonicola crista-galli* Wright ; *C.* cf. *crista-galli* ; *C. pseudorobusta* Trueman ; *C.* cf. *pseudorobusta* ; *C.* aff. *martini* Trueman and Weir ; *C.* cf. *martini* ; *C.* aff. *rhomboidalis* Hind ; and *C.* cf. *rhomboidalis*. One unusual elongated form of *C.* cf. *communis* Davies and Trueman was also collected. Typical representatives are illustrated in Text-fig. 2. The assemblage is clearly characteristic of the *C. pseudorobusta* Sub-zone of the upper part of the *C. communis* Zone.

A review of the palaeontological evidence linking the Midgeholme sequence with that of Northumberland and Durham will now be given. In Durham, the boundary between the *A. modiolaris* and *C. communis* Zones occurs between the Harvey and Busty seams. The Hopkins Shell Bed (above the Harvey Seam and often known as the Towneley in west Durham) with its typical *A. modiolaris* Zone assemblage has been correlated with the Craignook Shell Bed. If this correlation is correct the *A. modiolaris* Zone therefore is clearly represented in the Midgeholme field. Now reference to Plate IV opp. p. 99 in the Brampton Memoir shows that the Cannel Seam of Midgeholme is correlated with the Five-Quarter Seam of Durham recorded in the Chopwell composite section. The coals recorded as the Five-Quarter and Stone Coal in this section are names given to two seams in many parts of the north-west Durham portion of the field but which are usually known as the Top Busty and Bottom Busty (Hopkins, 1933, Table 1). When they coalesce, they form a thick seam known as the Busty. It is significant that in both the Midgeholme and Northumberland and Durham Coalfields, the highest known shell bed of the *C. communis* Zone should occur at the Busty horizon.

It is not, however, actually at the same precise horizon. The Durham shells listed by Hopkins from Medomsley and Byer Moor in north-west Durham, occur in the roof shales of the thick Busty Seam (1929, p. 131 ; 1930, pp. 102–3). We are indebted to Mr. G. Richardson who recently presented us with further material from Medomsley which included crushed forms resembling *Carbonicola* cf. *pseudorobusta*

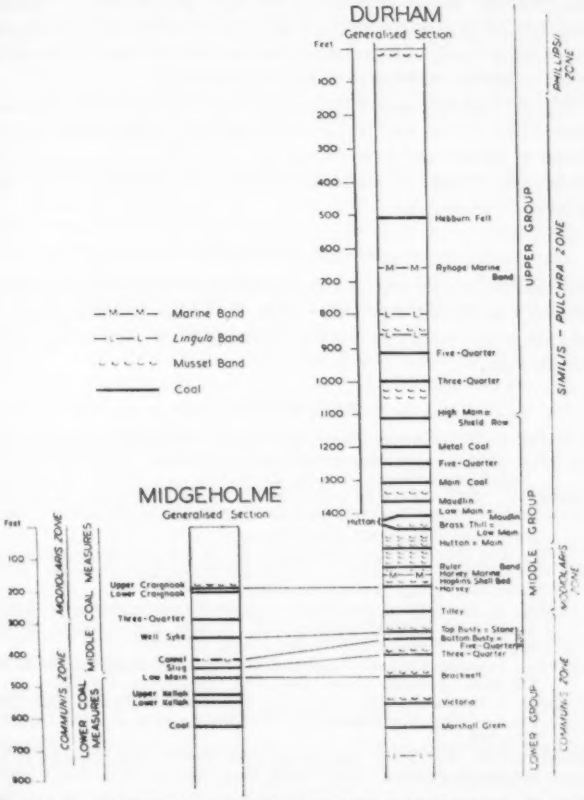


TEXT-FIG. 2.—Typical shells from the Cannel Seam Shell Bed, Midgeholme Colliery, Midgeholme.

Trueman. The Midgeholme shells are found in a parting in the equivalent of the Bottom Busty of Durham, i.e. at a depth of 60 feet below the Well Syke Seam which is shown by Trotter and Hollingworth as the equivalent of the Durham Top Busty Seam. Hind actually records *Carbonicola aquilina* from the Five-Quarter or Bottom Busty Seam at Heworth in the Durham field (1894–6, fig. 11, p. 163). Careful search has failed to find any shells in more recent workings at Heworth and in view of recent advances in nomenclature, we very much doubt

Hind's naming of his material which unfortunately does not now appear to be available for study.

In Northumberland and Durham typical assemblages of the *C. pseudorobusta* Sub-zone are also associated with the Three-Quarter



TEXT-FIG. 3.—Comparative generalized sections of the Durham and Midgeholme Coalfields.

Seam near the base of the Middle Group and the Brockwell and Victoria Seams in the highest beds of the Lower or Gannister Group (Hopkins, 1930, pp. 102–3, pl. vi; Hopkins and Philipson, 1947, p. 276), but they do not appear, as yet, to have a wide distribution over the field. On account of the paucity of fauna in the Lower Coal Group, the lower limit of the *C. communis* Zone cannot be recognized

in Northumberland and Durham. In the Midgeholme field, the Lower Coal Measures have so far proved to be destitute of shells and closely resemble the Lower Coal Group of Durham. The Cannel Seam Shell Bed of Midgeholme clearly shows that the lowest beds of the Middle Coal Measures can be referred to the upper part of the *C. communis* Zone, but as in Northumberland and Durham the base of this zone cannot be defined. The relationship between the two fields on the present available evidence is shown in Text-fig. 3.

Thus the available palaeontological evidence substantiates the views expressed by Trotter and Hollingworth that the Midgeholme sequence consists of Middle and Lower Coal Measures which correspond to the Middle and Lower or Gannister Groups of Northumberland and Durham.

ACKNOWLEDGMENTS

The authors tender their sincere thanks to the many members of the National Coal Board, especially to Mr. R. Taylor and also to Mr. G. Richardson for collecting further material from Medomsley in the Durham field.

REFERENCES

EASTWOOD, T., 1935. British Regional Geology, Northern England, p. 54.

HIND, W., 1894–6. A Monograph of *Carbonicola*, *Anthracomya*, and *Naiadites*. *Palaeont. Soc.*, fig. 11, p. 163.

HOPKINS, W., 1927. Further modifications of the correlation of the coal seams of the Northumberland and Durham Coalfield. *Trans. Inst. Min. Eng.*, lxxiv, 221–241.

—— 1929. The distribution and sequence of the non-marine lamellibranchs in the Coal Measures of Northumberland and Durham. *Trans. Inst. Min. Eng.*, lxxviii, 126–144.

—— 1930. A revision of the Upper Carboniferous non-marine lamellibranchs of Northumberland and Durham and a record of their sequence. *Trans. Inst. Min. Eng.*, lxxx, 101–110.

—— 1933. Impoverished areas of the Maudlin and Busty seams in the Durham Coalfield. *Trans. Inst. Min. Eng.*, lxxxv, 212–222.

—— and A. J. PHILIPSON, 1947. A record of the fossil shells and plants from the J sinking, Washington, C. Durham. *Trans. Inst. Min. Eng.*, cvi, 273–284.

TROTTER, F. M., and S. E. HOLLINGWORTH, 1932. The Geology of the Brampton District. *Mem. Geol. Surv.*, 98–112.

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The Pattern of Some Pacific Island Chains

By L. J. Chubb

Abstract

In certain Pacific island chains, characterized by feldspathoids in their volcanic rocks, the arrangement of the different types of islands conforms to a pattern which suggests that vulcanicity began at one end and moved progressively along the chain, erecting a series of volcanoes, each of which passed through a succession of stages, ending as an atoll. The origin of coral reefs is discussed in the light of these observations.

In an earlier communication (Chubb, 1934) it was shown that the island groups of the Pacific Ocean fall into four categories which are each confined within certain areas or zones, the Andesite Zone, the Nepheline-free Zone, the Nepheline-bearing Zone, and the Coral Island Zone. This paper is concerned primarily with the islands of the Nepheline-bearing Zone which include the Hawaiian, Caroline, Society, Samoan, Cook, and Austral groups.

In this zone the islands commonly form chains trending WNW–ESE, which are typically nearly straight, not arcuate as in the Andesite Zone. Within these chains a wide diversity of island types may be found, the extremes being atolls with no volcanic rock and active volcanoes with no reefs. Between these extremes many intermediate types occur, grading into each other by almost imperceptible degrees, and forming a sequence that completely bridges the gap. The various types are not scattered haphazard along the chains but are arranged in an orderly manner tending towards a definite pattern. No single chain shows this pattern in perfection, but every chain within the Nepheline-bearing Zone approaches it more or less closely. The ideal pattern will first be described, and then the modifications shown by the actual island-chains will be considered.

The Ideal Pattern

An ideal island-chain would be from 800 to 1,600 miles long and would trend approximately WNW–ESE. The islands at its western end would be atolls, built entirely of calcareous rock; eastwards these would be succeeded by islands of the type, called "almost-atolls" by the late W. M. Davis, consisting of a ring-shaped reef enclosing an extensive lagoon from which would arise a single islet, or a group of islets, composed of volcanic rock. Further east these would give place to volcanic islands, so deeply dissected and embayed that all trace of their original form was lost, surrounded by a broad lagoon enclosed within a barrier-reef. Continuing in the same direction larger volcanic islands would be found, less dissected, less embayed,

and with barrier-reefs lying closer to their shores. The succeeding islands would show their original volcanic form but little modified by erosion, with closely-set barrier or fringing-reefs, and in the more easterly of these the original ropy or blocky lava-surfaces would be almost unweathered, though there would be no record of volcanic activity within historic times. Towards the eastern end of the chain there would be volcanoes, perhaps with some coral-growth but no definite reefs, in which activity had been recorded by native tradition, or by the early European explorers ; the most easterly volcanoes would be active to-day.

Modifications of the Pattern

The Society or Tahiti chain differs from the ideal pattern in little except the absence of active volcanoes. The western islands, Fenua Ura, Motu One, Mopihaa, and Tubai are atolls ; eastwards these are succeeded first by Maupiti which is almost an atoll, with a volcanic islet in its lagoon, then by the small, deeply dissected and embayed volcanic island, Bora-Bora, reef-encircled, with a broad lagoon ; then come the progressively less dissected and less embayed volcanoes of Tahaa, Raiatea, Huahine, Moorea, and Tahiti, the last consisting of two volcanoes, both still showing their original volcanic form, and having an almost unindented shore-line. All these islands have barrier-reefs which in Tahaa extend to nearly two miles from shore, in the succeeding islands generally to about a mile, and around parts of Tahiti to only half a mile, becoming a fringing-reef in places. Finally, at the eastern end of the chain, lies Mehetia, a bold volcanic cone, hardly dissected and unembayed, with a narrow fringing-reef and a well-preserved crater from which many recent lava-flows have issued, though there is no record of any activity within human memory.

The Hawaiian chain shows a very complete sequence, but it is characterized by the absence of drowned river-valleys and of barrier-reefs, though fringing-reefs and atolls occur. The western islands, Kure, Midway, Pearl-and-Hermes, Lisianski, Laysan, and Maro are atolls ; eastwards these give place to the volcanic stacks, Gardner and La Pérouse, succeeded by the volcanic islets, Necker and Nihoa, and the rather larger island, Niihau. Eastward lies Kauai, an ancient volcano so deeply dissected that all trace of its original form is lost, and Oahu and Molokai, each composed of two volcanoes, of which the western is older and more dissected than the eastern. All these volcanoes are extinct, but in the next island, Maui, whereas the western volcano has not been active within human memory, the eastern, called Haleakala, was in eruption in 1750. The most easterly island, Hawaii, has two extinct volcanoes and three craters, of which the western, Hualalei, last erupted in 1801, the central, Mauna Loa,

erupts every four or five years, and the eastern, Kilauea, which contains a lake of molten lava, is almost continuously active. The only important embayment within the chain, Pearl Harbour in Oahu, is due, not to the drowning of a river-valley, but to the depression between the two volcanoes composing the island being still below the sea. This need have involved neither subsidence of the island nor a rise of sea-level.

The Samoan chain differs from the Hawaiian and all other groups in that the pattern is reversed, the only atoll, Rose Island, lying at the *eastern* end ; this is succeeded in a westerly direction first by the small volcanic islands, Ta'u, Olosenga, and Ofu, then by the deeply dissected Tutuila, which has one important embayment, Pango Pango, resembling Pearl Harbour. None of these have recognizable craters, but further west comes the larger Upolu with several, though with no record of volcanic activity ; finally, at the western end, Savai'i, the largest island in the chain, bears a number of craters which have erupted frequently within historic times. Fringing or barrier-reefs encircle most of the islands, but around Savai'i they are found only at the older eastern end.

The Caroline group for administrative purposes includes the Yap and Pelew islands, but these belong to the Andesite Zone, and are omitted from this discussion. Among the true Caroline islands atolls greatly predominate, all the western islands and most of the eastern being of this type, but among the eastern atolls lie three extinct volcanoes. Truk, near the centre of the chain, consists of about fourteen small islands and stacks composed of basalt rising from a lagoon within a barrier-reef some 40 miles in diameter. About 440 miles further east lies Ponape, a much dissected and embayed volcano, with a barrier-reef enclosing a lagoon up to three miles wide. At the eastern end of the chain, some 340 miles from Ponape, lies Kusaie, a volcanic island showing immature erosion, a relatively even coastline, and a fringing-reef.

The Tuamotu or Low archipelago consists of about seventy-five islands, nearly all of them atolls, a few attaining 100 miles in circumference. However, near the south-eastern end of this chain lies Mangareva, an old volcano in a similar stage of development to Truk, comprising about a dozen small embayed islands and stacks in a lagoon surrounded by a barrier-reef some 24 miles in diameter. Three hundred miles further east lies Pitcairn, an island without reefs and little eroded, whose original volcanic form is still discernible, though it is rent by faulting. No nepheline has been reported from any Mangareva or Pitcairn rock, so perhaps the pattern here extends into the Nepheline-free Zone.

The Cook group shows the characteristic pattern only in a modified

form. The north-western islands Palmerston, Manuae, and Takutea are indeed atolls, and Aitutaki is almost an atoll, while the south-eastern islands, Rarotonga, Atiu, Mitiaro, Mauke, and Mangaia are volcanic. But as has been shown (Marshall, 1927 and 1930 ; Chubb, 1934), this arrangement is associated with a tilting of the whole group about a NE–SW axis, the chief evidence being reefs on the volcanic islands, uplifted to heights varying from 20 to 200 feet according to their distance from the axis.

In the Austral group, too, while the most westerly island, Maria, is calcareous and the other islands are volcanic, the distribution of barrier, fringing, and uplifted reefs, of plateaux and embayments, can best be explained as due to a wave-like migration of the anticline on which the islands stand (Chubb, 1927 and 1934).

Thus it seems not unlikely that the Cook and Austral groups originally showed a pattern comparable to that of the Society and Hawaiian islands, but this pattern has been modified by subsequent regional earth-movements. These groups, having been discussed in previous communications, will not be further considered here.

Evolution of Islands and Chains

It is difficult to envisage the various island-types in one of these chains otherwise than as stages in an evolutionary process. It would seem that volcanic action started at one end of each chain, the western or north-western in every case except the Samoan ; thence it moved along the chain, generally in an easterly or south-easterly direction, erecting a succession of volcanoes on the sea-floor.

Each volcano in turn was built up until it arose above sea-level, as a high island. Then followed a succession of stages. As soon as it emerged the island was subjected to subaerial erosion, and generally it early acquired a fringing-reef. In time the volcano became extinct. Dissection of the island continued and subsidence of its foundations led to the drowning of the river-valleys and the retreat of the shore, causing the opening up of a lagoon between the island and its reef which, growing more or less vertically upwards, became converted into a barrier. Continued subsidence progressively reduced the island's size, extended the embayments, and widened the lagoon, until only the summits of the mountains, and eventually only the highest peak rose above sea-level. When at last this peak disappeared the barrier-reef became an atoll, and further subsidence did not greatly change its form. The cycle was completed.

As each individual island went through an evolutionary process, so did the island-chain as a whole. The cycle was initiated when the first volcano appeared above sea-level, and will be completed when the summit of the last volcano sinks beneath the surface, and the

group becomes a chain of atolls. Each of the groups discussed above can be referred approximately to its stage in the evolutionary cycle. Perhaps the Samoan chain should be regarded as the youngest; it has several active volcanoes and only one atoll. The Hawaiian chain shows more maturity in the much greater development of atolls, and the reduction of several volcanic islands to mere stacks; but the occurrence of active volcanoes is a youthful feature. It is probably a long-lived chain. The Society islands have advanced a stage further, in that the last volcano has apparently ceased activity. The Caroline islands represent a still more mature stage, with only three volcanoes, the latest of them extinct, among many atolls. The Tuamotu archipelago with its numerous atolls and two old volcanoes is probably the oldest of these chains.

Senile Island Chains

It is tempting to seek still older groups belonging to this series. They would consist of chains of atolls, but their affinity with the groups under discussion could only be proved by deep boring, for it would depend on the foundations of the atolls being submerged volcanoes some of whose rocks should perhaps contain actual or normative nepheline.

There are a number of atoll-chains in the Coral Island Zone, but their trend-lines differ somewhat from that of most of the nepheline-bearing volcanic chains and generally approximate to NW–SE. In the earlier paper (Chubb, 1934, p. 292) it was suggested that their trends were comparable with those of the Andesite Zone, but it is now doubted if this has any significance. It seems likely that these atolls are founded on submerged volcanoes of the nepheline-bearing series, and the differing trends are due to a gradual change in the direction of earth-movements during geological time, the earliest trend being nearly NNW–SSE, which changed in time through NW–SE to WNW–ESE.

The trend-lines of the Samoan, Hawaiian, Society, and Caroline chains approximate to N 70° W, that of the older Tuamotu archipelago is N 55° W. Among the atoll chains, the Line islands trend N 45° W and both the Gilbert and the Ellice islands N 40° W. In the Marshall islands the western or Ralik chain trends N 35° W and the eastern or Radak chain N 20° W.

If these atoll chains do indeed owe their origin to the completion of the evolutionary process outlined above, they must be among the oldest groups in the Pacific, and their earliest islands should be those at their north-western ends, where subsidence would have reached a maximum. Bikini atoll occupies this position in the Ralik chain. Geophysical tests (Ladd, Tracey, and Lill, 1949) have proved that the

foundation rocks of this atoll lie at a depth of 6,000 feet or more. In 1950 basaltic rocks were dredged from the slopes of Bikini at depths between 1,000 and 2,000 fathoms (Emery, Tracey, and Ladd, 1954). These were the first samples of igneous rock found on the slopes of any atoll in the central Pacific, and constitute the first direct evidence of the volcanic nature of the foundations on which these islands are built.

Still more definite evidence was obtained from Eniwetok atoll, which lies about 180 miles west of Bikini. Here two deep holes were drilled recently (Ladd *et al.*, 1953) on opposite sides of the island; that on the north-west, after penetrating 4,610 feet of Recent, Pleistocene, Pliocene, Miocene, and Eocene limestone, reached hard basement rock, of which no sample was recovered; that on the south-east passed through a similar limestone series to a depth of 4,154 feet where basalt cuttings were obtained, and a solid basalt core was recovered from 4,208 to 4,222 feet. This is a hard, black, unweathered basalt of a type common in the Pacific islands. Until a full petrographic description and chemical analysis is available, it will not be known whether the rock belongs to the nepheline-bearing or nepheline-free series.

The Origin of Coral Reefs

Nearly all the islands discussed in this paper must have originated in pre-glacial times, so they would be expected to furnish evidence of any post-glacial rise in seal-level. But this rise would have been everywhere equal, the sea cannot have risen by different amounts around different islands, yet the degree of drowning of the coasts and the stage in the development of reefs varies from island to island within any one chain. The only explanation of this fact is that each island subsided independently, and it would appear that among the central Pacific islands, subsidence is a usual sequel to volcanic action. It is presumably the result of the emptying of a magma reservoir, and the overloading of the superjacent crust with volcanic accumulations. The obvious fact that the transfer of material from below to above the crust must normally lead to subsidence of a volcano's foundation is lost sight of by those who oppose the subsidence theory of reef-formation. Further, the accumulation of a great mass of reef-material must itself form a very heavy load on a crust that has lost its support below. It does not follow that the circum-Pacific andesitic volcanoes have suffered subsidence, for they are associated with intense lateral pressure, which may have squeezed out the volcanic material, closing the sub-crustal vacuity simultaneously with the erection of the volcano, and in many cases actually raising its foundations.

One of the most significant facts that has emerged from the deep drilling on Eniwetok is that the fossils, including foraminifera, corals, echinoids, gastropods, lamellibranchs, crustacea, and calcareous algae, which were found at nearly every horizon throughout the limestone succession in both holes, were all shallow-water forms, such as would not normally live at the depths at which they were found. Several holes were drilled in Bikini atoll, the deepest attaining a depth of 2,556 feet (Ladd, Tracey, and Lill, 1949 ; Emery, Tracey, and Ladd, 1954). The drill passed through a continuous limestone succession from Recent to Oligocene and possibly Upper Eocene, and here, too, all the fossils were shallow-water forms. It may be remembered that the same was true of the organisms found in the hole drilled by the Royal Society Expedition in Funafuti in the Ellice Islands (Hinde, 1904), which reached a depth of 1,114 feet. Surely no further proof is needed that these atolls were all built on subsiding foundations.

Thus it would appear that the building of the existing atolls began in the Eocene. This is to be expected as modern types of reef-building organisms first appeared at that time. Recently, however, interesting proof has been forthcoming that subsidence of Pacific volcanic islands has been going on since earlier times. Hess has described flat-topped conical mountains, which rise as much as 10,000 feet above the floor of the Pacific Ocean, but whose summits may be 5,000 feet or more below the surface. He called them " guyots " (Hess, 1946), and interpreted them as ancient volcanic islands which had suffered profound subsidence. They are now known to be widespread in the north Pacific and their volcanic origin has been abundantly proved by the dredging from their sides or top of fragments of basaltic lava or tuff, which are often rounded into pebbles as though by wave action. Their flat tops, which are attributed to marine planation, have been successfully photographed and shown to be largely bare basalt platforms.

Hess suggested that the guyots might be as old as Pre-Cambrian but recent evidence shows that some are much younger. The U.S. Navy Mid-Pacific Expedition of 1950 discovered a mountainous region with many guyots between the Hawaiian and Marshall islands. From the margin of the flat tops of two of these guyots the expedition dredged a well-integrated fauna consisting or corals, rudists, stromatoporoids, gastropods, lamellibranchs, and an echinoid, the age of which was Aptian to Cenomanian (Dietz, Menard, and Hamilton, 1954). The assemblage is a shallow-water one, though now at a depth of a mile below the surface, and in each case fragments or rounded pebbles of basalt were recovered in the same haul or a nearby haul, so it would appear that these guyots are drowned basaltic platforms with marginal reefs of mid-Cretaceous age developed near sea-level, which have

since subsided to their present depth, but have never been covered by more recent deposits.

The poor development of coral-reefs around the volcanic Hawaiian islands remains a problem. Glacial moraines and striated pavements occur on Mauna Kea (13,825 feet), Hawaii, which even to-day is snow-covered in winter. Yet it seems hardly likely that the absence of barrier-reefs around the volcanic islands is due to Pleistocene chilling of the sea-water, as the atolls forming the western end of the chain lie in higher and cooler latitudes. Dietz and Menard (1953) have described submerged terraces at various depths from 180 to 700 fathoms around several of the islands, which they interpret as drowned shore-lines, indicating subsidence. But this is difficult to reconcile with the absence of drowned river-valleys, which suggests that the lack of barrier-reefs is due to the islands not having subsided. This could be brought about by lateral pressure, an hypothesis rejected by Dietz and Menard. No doubt future work will throw further light on the problem.

REFERENCES

Chubb, L. J., 1927. The Geology of the Austral or Tubuai Islands. *Quart. Journ. Geol. Soc.*, lxxxiii, 291–316.

—— 1934. The Structure of the Pacific Basin. *Geol. Mag.*, lxxi, 289–302.

Dietz, R. S., and H. W. Menard, 1953. Hawaiian Swell, Deep and Arch, and Subsidence of the Hawaiian Islands. *Journ. Geol.*, lxi, 99–113.

—— —— and E. L. Hamilton, 1954. Echograms of the Mid-Pacific Expedition. *Deep-Sea Research*, i, 258–272.

Emery, K. O., J. I. Tracey, and H. S. Ladd, 1954. Geology of Bikini and Nearby Atolls. *U.S. Geol. Survey*, Professional Paper 260–A.

Hess, H. H., 1946. Drowned Ancient Islands of the Pacific Basin. *Amer. Journ. Sci.*, ccxliv, 772–791.

Hinde, G. J., 1904. Report on the Materials from the Borings at the Funafuti Atoll. *The Atoll of Funafuti*, Section xi, *Royal Society*.

Ladd, H. S., J. I. Tracey, and G. G. Lill, 1949. Drilling on Bikini Atoll, Marshall Islands. *Science*, cvii, 51–5.

—— —— 1949. The Problem of Coral Reefs. *Scientific Monthly*, lxix, 297–305.

—— *et al.*, 1953. Drilling on Eniwetok Atoll, Marshall Islands. *Bull. Amer. Assoc. Petrol. Geol.*, xxxvii, 2257–2280.

Marshall, P., 1927. Geology of Mangaia. *Bernice P. Bishop Mus. Bull.*, xxxvi, 1–48.

—— 1930. Geology of Rarotonga and Atiu. *Bernice P. Bishop Mus. Bull.*, lxxii, 1–75.

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The Goniatite *Girtyoceras* cf. *weetsense* Moore from the shales above the Jew Limestone, Northumberland.

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Abstract

A new Yoredale goniatite locality in the shales above the Jew Limestone (Lower Carboniferous) at Temon, near Greenhead, Northumberland, has yielded a fauna including *Girtyoceras* cf. *weetsense* Moore ; a lower P_2 age (Bollandian) is indicated. The fauna and lithology of the goniatite-bearing shale is described and the lateral correlation of the Jew Limestone discussed. It is suggested that the base of the Jew (= Hardraw = Oxford) Limestone is the most satisfactory horizon for the P_1–P_2 boundary in the northern Pennines.

Introduction

An examination of the Carboniferous, Upper Bernician, Yoredale succession exposed in Poltross Burn during the summer of 1953 led to the discovery of a new goniatite locality in the shales above the Jew Limestone. Poltross Burn is a small northward flowing tributary of the River Irthing which crosses the Greenhead to Brampton road at Temon, $2\frac{7}{8}$ miles from Greenhead, where it forms the county boundary between Northumberland and Cumberland. The area was re-surveyed by the Geological Survey between 1923 and 1927 and is at the north-eastern corner of the Brampton Sheet (new series one-inch Sheet 18) ; a sheet memoir was published (Trotter and Hollingworth, 1932). In Poltross Burn the Yoredale, Middle Limestone Group, succession between the Bankhouses and Cockle Shell limestones is partly exposed (ibid., p. 67) and the shales of the Jew Cyclothem are particularly well seen. These shales crop out on the right (Northumberland) bank of the burn 140 yards up stream from the road bridge in the field behind Temon Farm ; the full national grid reference is 35/618638. About 20 feet of shales are exposed in a cliff above the burn and the Jew Limestone is visible in the stream bed.

The goniatite band is 2 feet thick and occurs 3 ft. 6 in. above the Jew Limestone in dark hard pyritic mudstone shales. The goniatites are sparsely scattered through the lower foot of shale from which some twenty-five specimens have been collected ; only two specimens have been found in the upper foot of shale. They are all fragmentary and crushed and consist of broken shell fragments of varying size on which the goniatite ornament is well preserved. In some cases several fragments occur together but no whole specimens have been found. Several of the goniatite fragments from this locality have been placed in the Geological Survey Museum in London where they are numbered Zl. 3478–91.

The Temon goniatites have been examined by Mr. W. S. Bisat,

Dr. W. H. C. Ramsbottom, and Dr. C. J. Stubblefield who agree that most of them are referable to *Girtyoceras* cf. *weetsense* Moore. Mr. Bisat adds that they compare well with a specimen determined as *G.* cf. *weetsense* [or closely allied species] collected by Mr. E. W. J. Moore from the shales 7 feet above the *Sudeticeras splendens* horizon (base of P_{2b}) in Newton Gill, 1 mile east of Long Preston, near Settle, Yorkshire ; the specimen is in the collection of the Geological Survey Museum in London and numbered 86953. Mr. Bisat also refers a single specimen from Temon (G.S.M. no. Zl. 3489) to cf. *Girtyoceras meslerianum* (Girty).

The type specimens of *G. weetsense* come from the *Sudeticeras splendens* band at the base of P_{2b} (Upper Bollandian) of Weets Hill, Barnoldswick, Yorkshire (Moore, 1946, p. 408). According to Moore (ibid., p. 440) the stratigraphical position of *G. weetsense* is above *Girtyoceras brüningianum* (H. Schmidt) and below *Girtyoceras multicameratum* Moore. In the absence of further information it would be suggested that the Temon goniatite fauna was probably of basal P_{2b} age but there remains the single specimen referred by Mr. Bisat to cf. *Girtyoceras meslerianum* (Girty). Specimens of *G. meslerianum* have been recorded by Moore (1946, p. 405) from the top of P_{1a} (Lower Bollandian) of Dinckley Ferry, Lancashire, and the presence of this species would indicate a position below P_{2b}. There is, therefore, with present knowledge of goniatite ranges, some uncertainty with respect to the exact horizon of the Temon fauna. They are regarded, however, as indicating a position low in the P_2 zone, Upper Bollandian (Upper Viséan). It will be shown that this is consistent with other goniatite records from the vicinity of the lateral equivalents of the Jew Limestone.

Succession and Lithology

The following sequence in the lower part of the Jew Cyclothem is exposed in Poltross Burn at Temon :—

Dark mudstone shale with bands of large septaria and scattered clay-ironstone nodules. Sparsely fossiliferous marine fauna, the fossils becoming rare in upward succession	18–20 feet
Dark pyritic mudstone shale with clay-ironstone nodules and septaria. Scattered marine fauna with fragmentary goniatites	2 feet
Dark non-calcareous mudstone shale with richly fossiliferous marine fauna. Only the upper 18 inches seen	3 ft. 6 in.
Jew Limestone, dark hard compact crinoidal limestone with small " *Girvanella* nodules " exposed in the stream bed.	

The upper member of the Jew Shales in Poltross Burn is a typical Yoredale dark shale with ironstone nodules and is here developed,

as is normally found, above the limestone and fossiliferous shales in the cyclothem. The usual sparse and scattered marine fauna of lamellibranchs, gastropods and brachiopods is present throughout this shale sequence. The pyritic mudstone shales below are of dark grey colour and weather dark blue with much iron staining. The pyrite is present as scattered fine particles and small discrete nodular masses in the shale ; small clay-ironstone nodules and septaria are fairly abundant. The shales are highly compacted and show this by the many areas of bright slicken (cloughy markings) which are conspicuous. The fauna is found either as scattered individuals or in small concentrations brought together in elongate patches as if by current action. Indications of current sorting are not infrequent in Yoredale mudstone shales and were described by Hudson (1941, p. 283) in the E_2 age shales of the Mirk Fell Beds of north-west Swaledale ; as Hudson (op. cit.) stressed, the original deposition and subsequent sorting of the fossils are regarded as penecontemporaneous. A fossiliferous dark mudstone shale occurs below the pyritic shale and contains a rich fauna of brachiopods, gastropods, and lamellibranchs. Only the upper 18 inches of this shale has been seen and this is non-calcareous, a calcareous shale is usually found directly above the Jew Limestone but in Poltross Burn this is unexposed.

The position of the goniatite-bearing shale is of interest because goniatites, some albeit immature and indeterminate, have been found by the author in pyritic shales, above the fossiliferous marine shale horizon, in five Yoredale cyclothems in the northern Pennines. Yoredale goniatites have been found at other horizons in the cyclothem but the pyritic shale facies appears to be a common horizon for their occurrence.

Associated Fauna

The marine fauna collected in association with the goniatites in the pyritic shale and the shales immediately above and below this band in the Jew Shales at Temon included the following species :—

Cornulites sp.

Achistrum sp. ; *Archaeocidaris urei* (Fleming) ; Crinoid ossicles up to 5 mm. in diameter.

Fenestella aff. *plebia* McCoy ; *Fenestella* sp. ; *Pennirétepora* sp. ; Stick bryozoa indet.

Chonetes hardrensis (Phillips) group ; *Chonetipustula* cf. *plicata* (Sarres, em. Kayser) ; *Cleiothyridina royssii* (Davidson) ; *Martinia* aff. *glabra* (Martin) ; *Orbiculoidea nitida* (Phillips) ; *Productus* (*Echinoconchus*) *elegans* ? McCoy ; *Productus* (*Eomarginifera*) *setosus* Phillips ; *Productus* (*Productus*) sp.

Aviculopecten interstitialis (Phillips) ; *Aviculopecten knockonniensis* (McCoy) ; *Aviculopecten* aff. *pera* (McCoy) ; *Leiopteria lunulata* (Phillips) ; *Limipecten dissimilis* (Fleming) ; *Nuculana attenuata* (Fleming) ; ?*Perno-*

pecten [*Syncyclonema*] *sowerbyi* (McCoy) ; *Pinna mutica* McCoy ; *Pseudamussium ellipticum* (Phillips) ; *Sanguinolites* sp.

Bucanopsis sp. ; *Dentalium* (*Plagioglypta*) cf. *priscum* (Münster) ; *Euphemites urei* (Fleming) ; *Glabrocingulum* cf. *armstrongi* E. G. Thomas ; *Glabrocingulum* aff. *atomarium* (Phillips) ; *Loxonema* sp. ; *Schizostoma catillus* (Martin).

Cycloceras sp. ; cf. *Girtyoceras meslerianum* (Girty) ; *Girtyoceras* cf. *weetsense* Moore ; Orthoconic nautiloids.

Ostracods

Palaeoniscid scales ; Pisces indet.

The lamellibranchs are noteworthy for the range of individuals present in the goniatite-bearing shales at Temon. The pectinids are particularly common and many indeterminate small and immature lamellibranchs occur. Gastropods are fairly abundant but the brachiopods are generally rarer. Of the latter *Eomarginifera setosus*, *Martinia* aff. *glabra*, and *Chonetipustula* cf. *plicata* are fairly numerous. Many crinoid ossicles are present in the shale though they are restricted in size to below 5 mm. in diameter ; the bryozoans are quite abundant but fragmentary. The shales may be regarded as having an enriched goniatite-lamellibranch fauna. A similar faunal phase has been recorded by Currie (1954, p. 529) as being associated with goniatites in the shales of the Scottish Carboniferous ; the faunal phase of the shales of the Mirk Fell Beds (Hudson, 1941, p. 283) is also of similar type.

An interesting detail concerning the Temon shale fauna is the presence of many near-microscopic calcareous holothurian elements ; these are concentrated in small patches on some shale surfaces and are also found singly. The majority are in the form of a perforated plate with rounded rim having an irregular oval or circular form ; a few elongate slender spicules were found in association with them. Holothurian elements of this type, referred to *Achistrum* sp., have been previously recorded from Yoredale shales but are not normally present in such quantity.

Lateral Correlation

The Jew Limestone was first described by Westgarth Forster (1809) in his section of strata of the " Lead Measures " of Weardale and the Westmorland Pennines ; later workers have correlated the Jew with the Hardraw Limestone of Wensleydale (see Turner, 1927 ; Dunham, 1948 ; Trotter, 1952, and Rayner, 1953). During the re-survey of the Brampton district by the Geological Survey the Jew Limestone was traced from the Westmorland Pennines into the Greenhead neighbourhood of western Northumberland. Eastwards from Greenhead the outcrop of the Middle Limestone Group, including the Jew Limestone, has recently been surveyed by the author as far as the River North Tyne ; an account of the geology of this area is in preparation. In

western Northumberland the Jew Limestone, called the "E" Limestone by the surveyors of the primary geological survey,[1] has been correlated with the Oxford Limestone of north Northumberland from the abundance of "*Girvanella* nodules" (algal form-genus *Osagia* Twenhofel), which are characteristic of both limestones. These algal nodules have been found over a considerable range of strata in western Northumberland but they reach a maximum in abundance in the Jew Limestone. Garwood (1910, p. 681) was the first to suggest a correlation between the Oxford Limestone and a limestone in the position of the Jew of western Northumberland and this correlation was again put forward by Hedley (1931, p. 233). No evidence to suggest that this correlation is unsatisfactory has been found during recent work and it is now accepted with confidence. It is noteworthy that the Oxford Limestone was also correlated directly with the Hardraw Limestone of Wensleydale by Gunn (1898, p. 346) who, in this early account, gives remarkably shrewd correlations of Yoredale strata.

The shales associated with both the Hardraw and Oxford limestones have yielded goniatites of stratigraphical value (Rayner, 1953, p. 285). Dr. R. G. S. Hudson collected a specimen of *Goniatites sphaericostriatus* Bisat from the shales below the Hardraw Limestone of Askrigg, Wensleydale (Dunham snd Stubblefield, 1945, p. 257); the age is P_1c Bollandian. In north Northumberland a single specimen of *Beyrichoceratoides truncatus* (Phillips) has been collected from the shales above the Oxford Limestone at Rock Middlesteads (Dunham, 1948, p. 11). The specimen is imperfect but this species has been recorded in both P_1 and P_2 (Currie, 1954). The age of these goniatites thus agrees favourably with that of the new record at Temon.

A comparison between the Askrigg and Temon goniatite records shows that the base of P_2 must lie in the vicinity of the Jew (= Hardraw) Limestone. Now in Yoredale cyclothems the base of the limestone members have been found to be the most reliably non-diachronous boundaries and the limestones are the accepted horizons for mapping and correlation. It is therefore suggested that the P_1–P_2 boundary be taken at the base of the Jew (= Oxford = Hardraw) Limestone of the northern Pennines. This satisfies the palaeontological evidence and is a well-defined and persistent horizon which has been recognized throughout the Carboniferous Yoredale outcrop from the Craven faults in the south to the Scottish Border. Moreover, this horizon is consistent with the P_1–P_2 boundary in Scotland. Currie (1954, p. 533) has shown on palaeontological evidence that this boundary is most satisfactorily placed at the base of the Hurlet (= Main) Limestone—a stratum for long regarded as the lateral equivalent of the

[1] See G.S. old series one-inch quarter sheet 106 N.E.; no sheet memoir was published.

Oxford Limestone of Northumberland (Macgregor, 1930; Trotter, 1952).

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REFERENCES

Currie, E. D., 1954. Scottish Carboniferous Goniatites. *Trans. Roy. Soc. Edinb.*, lxii, 527–602.

Dunham, K. C., 1948. The Geology of the Northern Pennine Orefield, Vol. I, Tyne to Stainmore. *Mem. Geol. Surv. Gt. Brit.*

—— and C. J. Stubblefield, 1945. The stratigraphy, structure, and mineralization of the Greenhow mining area, Yorkshire. *Quart. Journ. Geol. Soc.*, c, 209–268.

Forster, W., 1809. *A Treatise on a Section of Strata from Newcastle-on-Tyne to the Mountain of Cross Fell in Cumberland; with remarks on the Mineral Veins in general.* Alston.

Garwood, E. J., 1910. Northumberland and Durham. In *Geology in the Field*, Jubilee Volume of the Geologists' Association, 661–697.

Gunn, W., 1898. Notes on the correlation of the Lower Carboniferous Rocks of England and Scotland. *Geol. Mag.*, xxxv, 342–9.

Hedley, W. P., 1931. The Lower Carboniferous. In "Contributions to the Geology of Northumberland and Durham". *Proc. Geol. Assoc.*, xlii, 232–8.

Hudson, R. G. S., 1941. The Mirk Fell Beds (Namurian E_2) of Tan Hill, Yorkshire. *Proc. Yorks Geol. Soc.*, xxiv, 259–289.

Macgregor, M., 1930. Scottish Carboniferous Stratigraphy: an introduction to the study of the Carboniferous Rocks of Scotland. *Trans. Geol. Soc. Glasgow*, xviii, 442–558.

Moore, E. W. J., 1946. The Carboniferous Goniatite genera *Girtyoceras* and *Eumorphoceras*. *Proc. Yorks Geol. Soc.*, xxv, 387–445.

Rayner, D. H., 1953. The Lower Carboniferous Rocks of the North of England: a review. Ibid., xxviii, 231–315.

Trotter, F. M., 1952. Sedimentation facies in the Namurian of North-Western England and adjoining areas. *Liverpool and Manch. Geol. Journ.*, i, 77–102.

—— and S. E. Hollingworth, 1932. The Geology of the Brampton District. *Mem. Geol. Surv. Gt. Brit.*

Turner, J. S., 1927. The Lower Carboniferous succession in the Westmorland Pennines and the relations of the Pennine and Dent Faults. *Proc. Geol. Assoc.*, xxxviii, 339–374.

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Sutures and Septa in Jurassic Ammonite Systematics

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Abstract

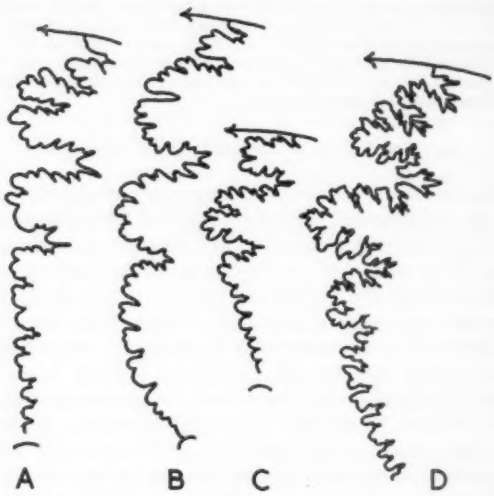
In the suborder Ammonitina the form of the septa and sutures is strongly influenced by whorl-shape and is often highly variable within the species and even the inidvidual. Claims that septa and sutures are specially significant because they are " internal characters " are refuted, as are also claims for overriding priority in classification for particular parts of the sutures, or for details of their early ontogenetic stages, or for the inner surfaces of the septa. Interpretation of the form of the septa and sutures as primarily conditioned by external water pressure is challenged. A recent revision of two superfamilies on the basis of septal form is held to involve unnatural groupings.

1. The Value of Sutures in Classification

THE general style of the sutures is a primary criterion for separating the two suborders Phylloceratina and Lytoceratina from the rest of the Jurassic Ammonoidea, the suborder Ammonitina. The elements of the sutures in the Phylloceratina are typically trifid and the saddle-endings are leaf-shaped (phylloid) ; in the Lytoceratina the elements are typically bifid and minutely frilled or " mossy ". These criteria are by no means infallible, however. For instance, some otherwise typical late Jurassic *Phylloceras* (e.g. *P. serum* (Oppel), *P. salima* Krumbeck) have almost entirely lost the phylloid saddle-endings, although by all their other shell characters, especially the ribbing, they cannot be separated from *Phylloceras sensu stricto*, and never have been so separated by any student of ammonites ; and many of the Cretaceous heteromorphs, which can be followed step by step from their origins in the Lytoceratidae, lose nearly all their Lytoceratid characters and have throughout ontogeny either very simple and bifid or minutely frilled but trifid suture elements.

Some palaeontologists have also attached overriding importance to suture lines at lower taxonomic levels in the Ammonitina, on the grounds that they are " an internal character ", less likely than other characters (whorl-shape, coiling, peristome, ribbing, etc.) to be influenced by environment. This assumption is highly questionable, because it has now been repeatedly shown that in many groups the general form of the suture line is primarily dependent on whorl-shape. Even in families widely separated stratigraphically and quite unrelated, shells with round or stout whorl section generally have similar sutures, with few or long lobes and saddles, while shells with compressed whorl section (oxycones, etc.) generally have numerous short lobes and saddles.

Thus Favre (1911) pointed out long ago the close resemblance between the sutures of discoidal *Oxynoticeras* (Sinemurian) and discoidal *Oppelia* (Bajocian) " without wishing to affirm that *Oppelia* descended directly from *Oxynoticeras* " ; and since then oxycones have been found in the Bathonian of Arabia with sutures virtually indistinguishable from those of *Oxynoticeras* although the ammonites are believed to be unrelated to either that genus or the Oppeliidae (Arkell, 1952, pp. 279–81) (Text-fig. 1). On the other hand, an attempt to



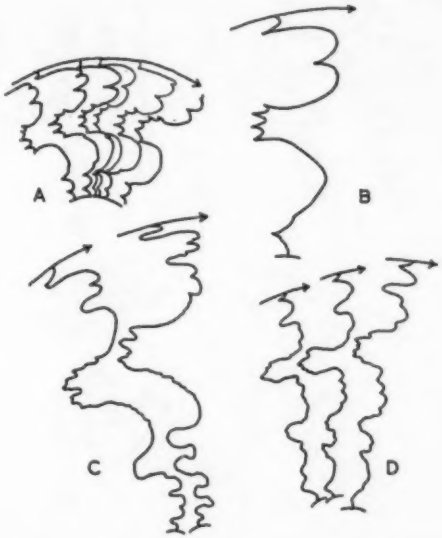
TEXT-FIG. 1.—Suture of Bathonian oxycones, A, B, and Sinemurian oxycones, C, D. A, *Thambites planus* ; B, *Thambites oxynotus* (both from Arabia) ; C, *Oxynoticeras* (*Fastigiceras*) *clausum* ; D, *O.* (*Metoxynoticeras*) *columellatum* (both from the English Lower Lias).

establish by detailed examination of the sutures the immediate ancestors in the Arietitidae of certain possibly polyphyletic Oxynoticeratidae (George, 1930) failed, because the Oxynoticeratidae have oxynoticeratan sutures and the Arietitidae have sutures that are quite different and appropriate to ammonites of essentially quadrate whorl-section.

Again, in the planulate, round- or quadrate-whorled Perisphinctaceae, from the Middle Bajocian to the top of the Jurassic " the same types of suture-line unfortunately recur continuously " (Spath, 1923, p. 302), and it is only in the occasional short-lived, high-whorled offshoots (such as *Ringsteadia*) that the sutures become notably shorter-lobed and more " serial " or " open ". On the other hand, in some obviously

Perisphinctacean genera (e.g. some *Procerites*) and also even in some discoidal Oppeliidae (e.g. *Uhligites*) the sutures may become extremely elaborate ("closed"), so that they are modified almost beyond recognition, without this denoting any fundamental difference of ancestry.

Another major modification of the sutures is exemplified by the pseudoceratites, which are now known to occur not only in the Albian

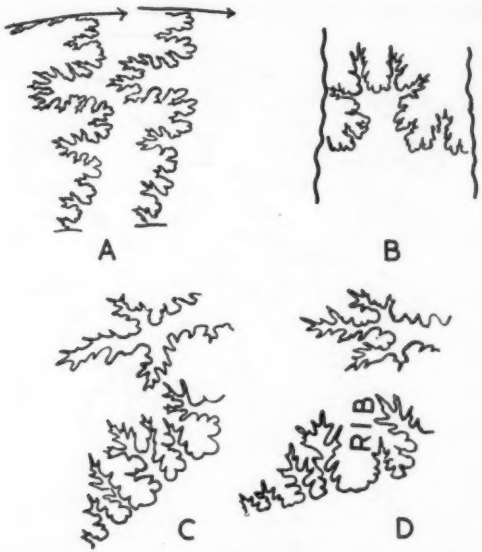


TEXT-FIG. 2.—Toarcian pseudoceratites and transitional forms of suture, from Arabia. A, B, *Bouleiceras* sp., A, showing irregular spacing of sutures. C, D, *Nejdia*, showing instability of sutures, especially in the umbilical lobe: C, sutures on opposite sides of the same specimen; D, sutures on opposite sides of another specimen.

and late Upper Cretaceous faunas but also in the Toarcian (*Bouleiceras*), the Sinemurian (*Hypasteroceras*) and Hettangian (*Psilophyllites*). Nothing could exceed the peculiarity of these sutures (Text-fig. 2), yet there can be no question of any close relationship between the different Jurassic forms, still less between them and the Cretaceous pseudoceratites or the Triassic ceratites; in fact all the Jurassic genera can be attached, by means of their other shell characters, to contemporary families.

In the thesis that the suture line of an ammonite is especially reliable

for systematic purposes it is implicit that suture lines are an exceptionally stable character within the species, genus, and family. This assumption has been disproved by numerous observations. In many species of different genera and families it has been found that in one and the same individual suture lines may be highly variable in several ways : for instance, (1) in their spacing, which determines the length

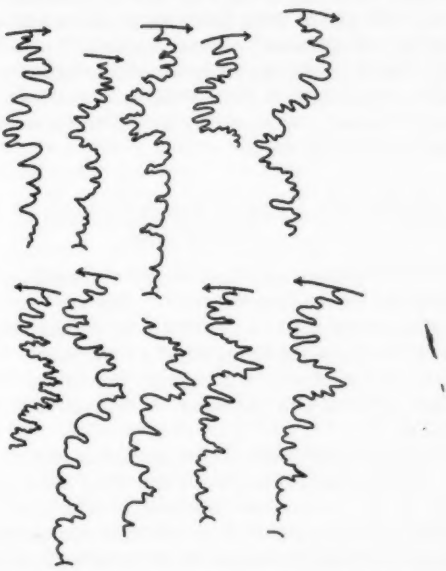


TEXT-FIG. 3.—A, sutures on opposite sides of a *Pictonia*, showing consistent difference in the first lateral lobes. B, venter of an otherwise normal *Perisphinctes* with displaced ventral lobes, which necessarily involves distortion of the rest of the external suture. C, D, sutures (separated by two camerae) on same side of a *Perisphinctes*, showing instability in the umbilical lobe, due apparently to position of a large rib. (Traced from Arkell, 1935–48, pl. A.)

of the camerae, or gas chambers (Text-fig. 2A) ; (2) in their symmetry on opposite sides of the whorl, which varies with excentricities of the siphuncle (Text-fig. 3B) ; (3) in the general plan and detail of the lobes on opposite sides of the whorl, which may occasionally be consistently quite different, without indications of any other abnormality in the shell (Text-figs. 2C, 3A) ; (4) in the spacing and direction of the second lateral and auxiliary lobes, which varies according to the position of dorso-lateral tubercles or large ribs (Text-fig. 3C, D) ; (5) in the relative and overall lengths of the lobes during successive

stages of growth of the shell, as may be seen by painting sutures on umbilical and outer whorls of many ammonites (Arkell, 1935–48, pl. A, figs. 1a, 1b).

At specific level some striking variations may also be found. For instance, in the common Bathonian species, *Morrisiceras morrisi* (Oppel), some individuals have a widestemmed, bifid second lateral lobe while others, identical otherwise in every way and found with



TEXT-FIG. 4.—Sutures of different specimens (otherwise indistinguishable) of *Clydoniceras discus* from the English Cornbrash, showing variability and tendency to form a bifid first lateral lobe (var. *hochstetteri* Oppel). (Traced from Arkell, 1951–7, pls. ii, iii.)

them at the same horizon, have this lobe narrow and single-pointed. The single-pointed type of lobe is characteristic of the Macrocephalitidae, of which *Morrisiceras* is believed to be the earliest genus, while the bifid type of lobe is characteristic of the ancestral cadicone Tulitidae. It is believed that the species *M. morrisi* is transitional between the two families and that its unstable second lateral lobe is connected with adaptation of the septa to the transition from the stout cadicone tulitid whorl-shape to the more compressed macrocephaloid whorl-shape (Arkell, 1951–7, p. 113).

Again, in some oxycones such as *Clydoniceras* the sutures are so variable that scarcely two specimens can be found alike (ibid., pls. 1–3). In this genus (Text-fig. 4) a common variety within the species is a more or less bifid first lateral lobe—a character important at suborder level for distinguishing the Lytoceratina.

From all this it is evident that suture lines in the Ammonitina, while often an important character for classification, are no more stable or reliable than other characters such as ribs, constrictions, peristome, keels, etc., and that at times they may be completely misleading. In any case, to call them an " internal character " with the implication that they were sheltered from external environmental influences, or in any way comparable with parts of the unknown living tissues of the animal, is fallacious ; they were as external to the animal as were any other hard parts of the shell.

2. The Relative Value of Different Parts of the Septum and Suture

From time to time some students of ammonites succumb to the temptation to believe that the more " internal ", and therefore the more inaccessible, parts of a suture (or of the septum of which the suture is merely the frilled edge) are necessarily more important than the visible parts, and affirm that some feature newly discovered by laborious dissection is of overriding importance in classification.

First Salfield (1924) asserted that the dorsal part of the suture was the key to ammonite phylogeny. This part of the suture is normally not seen except in detached fragments of whorl, and consequently no material could be classified on this basis without breaking up the specimens. Fortunately, before all the collections in museums were destroyed, it was realized that the dorsal part of the suture was usually no more significant than the lateral and ventral parts.

Secondly Schindewolf (1951, 1953, and previous papers), on dissecting certain ammonites septum by septum, found that at the very earliest stages after the protoconch (i.e. at the beginning of the conch or phragmocone) the first few septa show a difference in the order of development of some of the minute folds of the umbilical lobe. On this basis he divided the ammonites into two main groups, which he called orthochrons and heterochrons ; and he defended the overriding importance which he attached to this difference on the grounds that because it occurs at an early stage of ontogeny it is " independent of changes in shell form and mode of life " (Schindewolf, 1953, p. 126).

Now if a character with only two possible variants is to have priority

among systematic criteria in the suborder Ammonitina it either requires a new systematic category between suborder and superfamily or must be used in combination with other characters for two groups of superfamilies. However, even the small number of genera so far dissected, as Schindewolf's lists show (1953, p. 127), preclude the possibility of any such classification. For the category " orthochrons " unites not only a random selection of Middle Jurassic to Lower Cretaceous Perisphinctaceae (the Callovian *Grossouvria*, Kimeridgian *Rasenia*, Tithonian *Berriasella*, Neocomian *Lyticoceras* and *Polyptychites*), but also the later Cretaceous *Desmoceras* and *Schloenbachia*, which all authorities have agreed are totally unrelated to the Perisphinctaceae. If " orthochrons " unite such diverse families, it seems totally unrealistic to separate, as unrelated, some nearly contemporaneous and hardly distinguishable perisphinctids because some are " orthochrons " and some " heterochrons ".

Westermann (1956, p. 246) concludes on other grounds that orthochrony and heterochrony cannot be used for definition of superfamilies, but he considers them a valid criterion for the recognition of families. Some may prefer the verdict of Spath (1931, pp. 280, 397) that this is only " an unimportant and variable feature ", another manifestation of the " plastic young ", and think that one might as well classify all ammonites as ribbed or unribbed, constricted or unconstricted, keeled or unkeeled, auriculate or non-auriculate, or with or without a ventral groove or a septal lobe. All such characters are useful at specific or generic, sometimes family, level, but only if used with discretion, and none can be accorded overriding priority in all the ramifications of the Ammonoidea or even Ammonitina, without producing a highly artificial classification.

A third appeal to obscure parts, the inner surfaces of the septa, to supply the key to ammonite phylogeny and classification, has now been made by Westermann (1956). He emphasizes the truism that sutures are not a distinct element of the ammonite shell but merely the edges of the septa, where those are attached to the inside of the whorl ; and concludes that therefore the important element is the septum, which must be dissected out to reveal its relatively simple and unfrilled median surfaces. Building on the well-known essay by Pfaff (1911), who distinguished two main types of septal design, the " centrally supported " and " laterally supported ", he asserts that " the septum conditions all the essential shell characters, even the ornament ", and that Pfaff's two types of septum " represent the highest-ranking character in the suborder Ammonitina " (Westermann, 1956, p. 237).

These are remarkable assertions. The more remarkable is the first, considering that the septa are not formed until the whorl has grown

from half to a whole turn (or more) beyond the point at which each septum is inserted, as the animal moves forward with the growth of the body chamber. The " essential shell characters, even the ornament " are therefore all developed and fixed immutably long before the septa are inserted. Pfaff made no such absurd claim ; on the contrary, he stated (1911, p. 222) : " From all the foregoing considerations it follows that the form of the septa and their suture lines is absolutely dependent on the shape of the whorl section, the degree of involution, and the strength of the last septum." (The last factor depends on Pfaff's theory of resistance to water-pressure, which will be considered below.)

Therefore, so far from " conditioning all the essential shell characters ", the septa are conditioned by the shape of the whorl into which they have to fit. The hidden inner surfaces of the septa contain no mysterious key to phylogeny ; their undulations, to which a ponderous terminology has been applied, are insignificant consequences of adaptation to whorl-shape, and in any case they are only incipient in the nodal median region of the septa and become much more fully developed towards the septal edges, where they reach their climax at the sutures.

Pfaff's essay gives no support to the notion that the septa and their sutures are an expression of genetic tendencies and were shielded by their internal position from external influences, for he ends it with the following sentence : " The whole of these researches proves that the septa and their sutures are perfect examples of adaptation, of which the details and changes can be demonstrated with mathematical precision, to the given external conditions, in this case water-pressure." While the first part of this sentence appears to be unanswerable, the second part is highly questionable, and will be examined in Section 3.

3. Interpretation of the Forms of Septa and Sutures

The essay by Pfaff (1911) which Westermann (1956) builds on and extends (with modifications from Schindewolf's views referred to above) consists of a mathematical examination of the septal surfaces of certain ammonites of different whorl section. Pfaff evaluates these in the light of the laws of strength and elasticity, and concludes that the septa of all ammonites are formed precisely so as best to resist external water pressure at the back of the body chamber and transmit it to the shell walls.

This conclusion, however, was not reached through an unbiased examination of the mathematical properties of the septal surfaces, but was preceded by arguments against the alternative hypothesis

that the animal was able to counteract external water pressure by building up gas pressures within the camerae. Against this hypothesis Pfaff raised the three following objections :—

"1. In *Nautilus pompilius* no organ has yet been discovered which could act as a kind of compression pump to build up such pressures in the camerae, in excess of atmospheric pressure."

"2. Examination of the siphuncle shows no openings, without which such a circulation of gas could not take place."

[3]. "Since the ammonites are ideally adapted in their whole structure and down to the smallest details to resist water pressure from outside, and since they have thin shells, they would burst when they rose rapidly towards the surface of the sea if the camerae contained gas at high pressure."

None of these arguments bears examination. They can be refuted as follows (Arkell, 1949, p. 409) :—

1. Atmospheric pressure has no relevance below the surface of the sea. At depth the external pressure is determined by the weight of the overlying column of water, and if the gas in the camerae started at atmospheric pressure, the internal pressure could be brought up to equal the external by the animal's merely generating gas, which would then be sucked into the camerae until pressures were equal (see 2).

2. Although no perforations in the siphuncle are visible, it is recorded that when a camera of a living *Nautilus* is punctured under water, gas bubbles out (Willey, 1902, p. 747). The fact that in fossil ammonites the siphuncle sheath differs from all the rest of the shell by being phosphatic suggests that it had a special composition for a special function, which may have been the transmission or even generation and reabsorption of gas in response to changing pressures inside and out. (See also Stenzel, 1952, pp. H 11–12.)

3. If one wished to design a means of preventing the ammonite whorls from bursting when the animal swam rapidly upward, one could scarcely devise anything more perfect than the frilled and interlocking edges of the septa, which afford maximum attachment of the septa to the whorls. Besides this they are built into the shell wall in such a way (Hölder, 1952) as to provide a superbly strong structure. Moreover, the fact that in all ammonites the septa are convex forwards, and that the forwardly directed frills (saddles) are more rounded than the backwardly directed (lobes), suggests that during their formation the membrane secreting the septa was under the influence of pressure from within rather than from without.

4. Phylogeny of the Stephanocerataceae and Perisphinctaceae based on Septa and Sutures

Dr. Westermann (1956) illustrates the application to phylogeny of his elaboration of Pfaff's observations on the septa, combined with a modification of Schindewolf's observations on the early ontogeny of the umbilical lobe, by setting forth a revised classification of the superfamilies Stephanocerataceae and Perisphinctaceae of the Middle Jurassic. This classification calls for comments of wider scope than are appropriate for the concluding part of my monograph on the English Bathonian ammonites (Arkell, 1950–?57, shortly to go to press, and completed in MS. before the appearance of Westermann's paper), and in defence of the classification adopted in the Treatise of Invertebrate Paleontology (Arkell, 1957, in the press 1955).

Stephanocerataceae

Two of the principal new features are the setting up of two new subfamilies, Normannitinae Westermann, split off from the Otoitidae and transferred to Stephanoceratidae, and Cadomitinae Westermann, split off from Stephanoceratidae. These changes arise in part out of Westermann's previously published (1954) monograph of the Otoitidae. After prolonged study of the figures and text of this monograph and correspondence with the author in quest of enlightenment, I was unable to grasp the differences between a number of his genera and subgenera, which seem to me redundant and undefinable, and consequently I adopted a conversative line in the Treatise (Arkell, 1957). No more need be said of these taxa here, except to remark that the separation of *Normannites* and its synonyms (or subgenera: the distinction is purely subjective) from the family Otoitidae seems unnatural, in view of the difficulty of separating *Normannites* from *Otoites* and the apparent passage from one into the other (discussed Arkell, 1954, pp. 568–572). The same objection applies even more strongly to the erection of a new subfamily Cadomitinae for *Cadomites* and *Polyplectites*, for the distinction of *Cadomites* from *Stephanoceras* is so delicate that were it not for the existence of the early established generic name *Cadomites* probably no authors would have attempted to make it; and there are still hardly any that succeed in using the name *Cadomites* correctly, without embracing in it some of the prior-named *Stephanoceras*.

In the Macrocephalitidae Westermann splits off *Morrisiceras* and *Lycetticeras* as a new subfamily Morrisiceratinae Westermann (called "Morrisiceratidae n. subgen.", p. 262), a move which adds nothing to the interest of these genera as the earliest Macrocephalitidae, showing affinities with the presumably ancestral Tulitidae. The most extraordinary feature in the whole paper, however, is the erection of a new

subfamily Berbericeratinae Westermann of the Macrocephalitidae, to contain the three Bathonian genera *Berbericeras*, *Schwandorfia*, and *Krumbeckia*. Of these *Berbericeras* is certainly, by all its externally visible characters, a perisphinctid, and although I first followed Roman in placing it provisionally in the Morphoceratidae (Perisphinctaceae), study of further material has made it reasonably certain that *Berbericeras* is a perisphinctid close to *Siemiradzkia*. As to the other two genera, both from the Middle Bathonian, I see no reason for changing the conclusion previously arrived at that they are dwarf and aberrant forms of the contemporary Tulitidae.

Of the later Stephanoceratacean families, Cardioceratidae, Pachyceratidae, and Kosmoceratidae, Dr. Westermann has nothing new to say, but has introduced a number of errors (p. 264). It should be noted that the names *Arcticoceras ishmae*, *Pavloviceras*, *Korythoceras*, and *Pachyceras lalandeanum* (and *Grossouvria* on p. 269) are misspelt; that wrong type species are cited for the genera *Quenstedtoceras* and *Kepplerites*; that *Vertumniceras* is shown as a subgenus of *Quenstedtoceras* whereas its type species is a subjective synonym of the (correct) type species of *Quenstedtoceras*; that *Lamberticeras*, a usefully separable subgenus, is listed as a synonym of *Quenstedtoceras*; that *Ammonites gowerianus* Sowerby is made (wrongly) to do duty as the type species of the genus *Kepplerites*, although Buckman's subgenus *Gowericeras* is retained.

Perisphinctaceae

As a revision of the Perisphinctaceae of the "Dogger" (which includes the Callovian), this part of the paper is very incomplete and appears to be based on insufficient information.[1] The principal innovation is a new subfamily Bigotitinae Westermann of Parkinsoniidae Buckman; but *Bigotites* Nicolesco (for which Westermann cites the wrong type species) belongs in my opinion to the Leptosphinctinae Arkell, 1950, and was an integral part of that subfamily as originally conceived. Under Morphoceratidae is also a new subfamily Oecoptychiinae Westermann, 1956, of which Oecoptychiinae Arkell, 1957 (Treatise), will be a junior synonymous homonym. The inclusion of this group in the Morphoceratidae (Perisphinctaceae), however, is highly questionable and insufficiently supported.

Less important points to be noted are three new genera and subgenera of Leptosphinctinae, erected without previous examination of

[1] Dr. Westermann was aware that my revision of the Bajocian and Bathonian perisphinctids was completed in MS. and ready for early publication by the Palaeontographical Society, and that all the genera and their type species would be appearing in the Treatise volume to be issued in 1957.

the numerous English Upper Bajocian forms to which Buckman had already given generic names. "*Praeleptosphinctes*" Westermann for the Argentine form discussed by me (Arkell, 1954, p. 591), like "*Praetulites*" Westermann for an Indonesian ammonite (see Arkell, 1954, p. 583), is insufficiently characterized, and while Westermann states that it differs from *Leptosphinctes leptus* Buckman, he does not compare it with *L. davidsoni* Buckman which, as I pointed out, it so closely resembles.

Dr. Westermann claims (1956, p. 267) that the simple peristome of these typical *Leptosphinctes* is confined to the adult while small forms with large lateral lappets and markedly different ribbing such as *L. cleistus* Buckman (type of the genus *Cleistosphinctes* Arkell, 1953) are apparently the young. It is a pity that he withholds the evidence for this important conclusion, which in principle was rebutted by Pompeckj in the classic paper on peristomes published in 1894.

Dr. Westermann's announcement (p. 262) of the first known *Reineckeia* from the Bathonian is based on a nucleus 11 mm. in diameter, which through the kindness of Dr. K. Hoffmann I was able to examine in July, 1956. It is too small for positive identification, but in my opinion it is a *Parkinsonia*.

5. Conclusions

The septa and their frilled edges (sutures) are an important character in classification of Mesozoic ammonites, especially at the highest taxonomic level (suborders), but they constitute only one of a number of at least equally significant morphological characters. Below the level of the suborders no case has been made out for giving them overriding priority in phylogeny and taxonomy.

Septa and sutures, like all other ammonite characters yet recognized —coiling, whorl shape, aperture, ribs, keels, furrows, etc.—are subject to wide individual variation, to changes during individual ontogeny, and to repetition of different variants at all levels in the phylogenetic tree and stratigraphical column. No single key to phylogeny has yet been discovered. Each character must be evaluated in relation to the whole combination in which it occurs. In one context (stratigraphical and morphological) one character may be most significant, in other contexts other characters. If I may express a general preference, based on a somewhat lengthy experience, it is for style of ribbing; and in this I am not alone. For instance, although a strong keel is a basic character of the Hildoceratacеae, we are not misled when a keelless genus turns up, having the characteristic ribbing and tuberculation of the Sonniniidae (*Zurcheria*) or Hildoceratidae (*Praehaploceras*), nor when by some freak we are confronted with a keeled perisphinctid

such as *Ataxioceras* (de Loriol, 1876–8, pl. x, fig. 10a), or *Polysphinctites* (Arkell, 1951–7, p. 139, fig. 52), or even a keeled *Aspidoceras* (Quenstedt, 1887, pl. 94, fig. 50). Similarly, if a ceratitic suture suddenly appears in the Jurassic we do not imagine that it is a Triassic survival. It is very seldom, however, that the style of ribbing leaves any doubt about the superfamily in which an ammonite should be placed.

Ammonites are the most sensitive clock we possess for relative dating in Mesozoic stratigraphy. Like all sensitive instruments they demand sensitive handling and some experience to make them work and to interpret their information aright. Attempts to extract this information by mechanical or rule-of-thumb methods will mislead the inexperienced and let slip much that could be of value for stratigraphy.

6. Acknowledgments

I am much indebted to Mr. C. W. Wright, Dr. D. T. Donovan, and Dr. J. H. Callomon for reading this paper in draft and for helpful criticisms and comments.

REFERENCES

Arkell, W. J., 1935–48. *Monograph on the ammonites of the English Corallian Beds.* Palaeontogr. Soc.

—— 1949. Jurassic Ammonites in 1949. *Sci. Progr.*, No. 147, 401.

—— 1951–7. *Monograph of the English Bathonian Ammonites.* Palaeontogr. Soc.

—— 1952. Jurassic ammonites from Jebel Tuwaiq, Central Arabia. *Phil. Trans. Roy. Soc.* (B), ccxxxvi, 241.

—— 1954. The Bajocian ammonites of Western Australia. Ibid. (B), ccxxxvii, 547.

—— 1957 Introduction to Mesozoic Ammonoidea ; *and* Systematic descriptions (Jurassic part). In *Treatise on Invertebrate Paleontology*, ed. R. C. Moore, part L.

Favre, F., 1911. Rapport entre les cloisons d'*Oppelia subradiata* Sow. et celles de quelques *Oxynoticeras* liasiques. *C. R. Acad. Sci. Paris*, clii, 1069.

George, T. N., 1930. The ontogeny of certain Arietidan Oxycones. *Geol. Mag.*, lxvii, 352.

Hölder, H., 1952. Über Gehäusebau, insbesondere Hohlkiel, jurassischer Ammoniten, *Palaeontographica* (A), cii, 18.

Loriol, P. de, 1876–8. Monographie paléontologique des couches de la zone à *Ammonites tenuilobatus* de Baden (Argovie). *Mém. Soc. Pal. Suisse*, iii.

Pfaff, E., 1911. Über Form und Bau der Ammonitensepten und ihre Beziehungen zur Suturlinie. 4 *Jahresber. Niedersächsischen Geol. Ver. Hannover*, 208.

Pompeckj, J. F., 1894. Über Ammonoideen mit anormaler Wohnkammer. *Jahresh. Vereins vaterl. Naturk. Württemberg*, xlix, 220 (and Habilitationsschrift z. Erl. d. Venia Legendi, Ludwig-Maximilians-Univ. München (Stuttgart)).

QUENSTEDT, F. A., 1883–8. *Die Ammoniten des Schwäbischen Jura.* 3 vols., Atlas (Stuttgart).

SALFELD, H., 1924. *Die Bedeutung der Konservativstämme für die Stammesentwicklung der Ammonoideen.* (Leipzig.)

SCHINDEWOLF, O. H., 1951. Zur Morphogenie und Terminologie der Ammoneen-Lobenlinie. *Pal. Zeitschr.*, xxv, 11.

—— 1953. Über *Strenoceras* und andere Dogger-Ammoniten. *N. Jahrb. Geol. Pal., Mh.*, iii, 119.

SPATH, L. F., 1923. On ammonites from New Zealand. *Quart. Journ. Geol. Soc.*, lxxix, 286.

—— 1931. Revision of the Jurassic cephalopod fauna of Kachh (Cutch), part iv. *Pal. Indica* (N.S.), vol. ix, mem. 2, 279.

STENZEL, H. B., 1952. Living Nautilus. Preprint of chapter in Part H, *Treatise on Invertebrate Paleontology*, ed. R. C. Moore.

WESTERMANN, G., 1954. Monographie der Otoitidae (Ammonoidea). *Beihefte zum Geol. Jahrb.*, Heft 15. (Hannover.)

—— 1956. Phylogenie der Stephanoceratacеae und Perisphinctaceae des Dogger. *Neues Jb. Geol. u. Pal., Abh.* 103, 233.

WILLEY, A., 1902. Contribution to the natural history of the pearly nautilus. *Zool. Results Materials New Britain, New Guinea*, etc., vi, 691. (Cambridge.)

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Structure and Form of Cheung Chau Island, Hong Kong

By Leonard Berry and Bryan P. Ruxton

(PLATE VIII)

Abstract

A study of Cheung Chau Island has revealed a close adjustment between the form of the island and the geological structure. The island is made up of dominant granite cut by granite-porphyry and dolerite dykes, which are affected by later faulting. A theory of progressive emergence is put forward for the denudation chronology of the area and the various forms related to the former submergence have been mapped. The relation of coastal and inland forms to structure is considered, and the evolution of the coast is outlined.

I. Introduction

CHEUNG CHAU Island, lying some eight miles to the south-west of Hong Kong Island, forms part of the New Territories of the Colony of Hong Kong (Text-fig. 1). It is really two islands, north and south, joined by a sand and gravel tombolo. In relation to its area of 0·96 square miles, Cheung Chau has a long coastline (about 10 miles) and much of this provides excellent exposures of bed rock. Cheung Chau has been studied as an area in which the geology and geomorphological history are similar to parts of the adjacent Lan Tau Island, and also as the best example of a tombolo found in local shoreline features.

Mr. Berry has been responsible for the geomorphological studies and Mr. Ruxton for the geological work; while both have co-operated on the remainder of the paper. Acknowledgments are made to the Research Grants Committee of the University of Hong Kong for financial assistance in obtaining instruments and photostats.

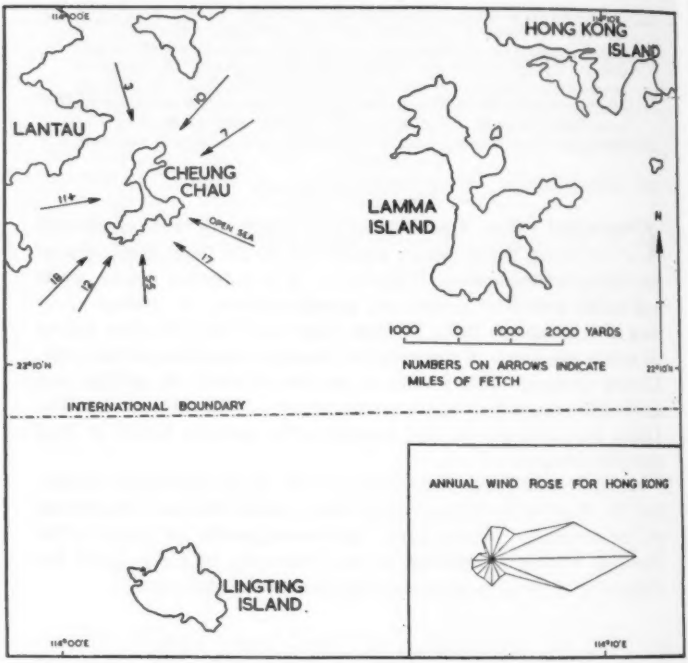
II. The Geology of Cheung Chau Island

(*a*) *Petrography*

Cheung Chau Island is made up predominantly of granite with subordinate microgranite, minor quartz-porphyry dykes, and a few basic dykes. The granite is a pinkish-grey, medium-grained rock having a xenomorphic-granular texture. Associated with it, without transition and with sharp contacts, are irregular and dyke-like masses of microgranite usually of a light pink or fawn colour.

The granite-porphyry and the quartz-porphyry form a series of long thin branching dykes trending generally ENE–WSW, varying in width from a few feet up to some 300 feet, and are variably chilled on contact with the granite and microgranite. The groundmass, some-

times quite coarse and "structureless" in the centre with granularity of about 1 mm., decreases to cryptocrystalline near contacts and develops a good fluxion structure parallel to the dyke walls. The granite-porphyries hold xenoliths of granite in them and the granite is hardened within a few feet of the contact.



TEXT-FIG. 1.—Location map of Cheung Chau Island.

The fine-grained basic dykes, which vary in width from a few inches up to 30 feet, are usually much altered to chlorite, epidote, calcite, and iron ore. A fresh specimen from the south-east coast was a quartz-pigeonite-dolerite and all would appear to be of this type. They cut the granite and at one locality on the south coast the granite-porphyry as well. But in places they form the outer margins of composite dykes with the granite-porphyries and then the relationships are obscure.

(*b*) *Structure*

In general the major jointing in the granite is nearly vertical, two prominent sets trending in a northerly and an easterly direction, with variably developed sheet jointing. The joint planes are commonly over ten feet apart. The granite-porphyry dykes usually show two sets of well developed, vertical, diagonal joints making angles of from 35° to 55° with the contacts. The joint spacing, sometimes only a few inches near the contact, increases towards the centre of the dykes.

This simple picture has been modified by later shearing, dominantly in an ENE direction. This expresses itself as prominent shear joints in the granite, in the dykes, and along the contacts which frequently show polishing and grooving. In places the granite is severely crushed and partially drawn out along these fractures.

At a later date the area was affected by northerly trending faults which have offset the dykes and the shear zones. The outline of the structural history is as follows:—

Vertical faulting—mainly NW quadrant.
Shearing—mainly NE quadrant.
Dyke intrusion—probably associated with, though later than, the jointing in the granite.

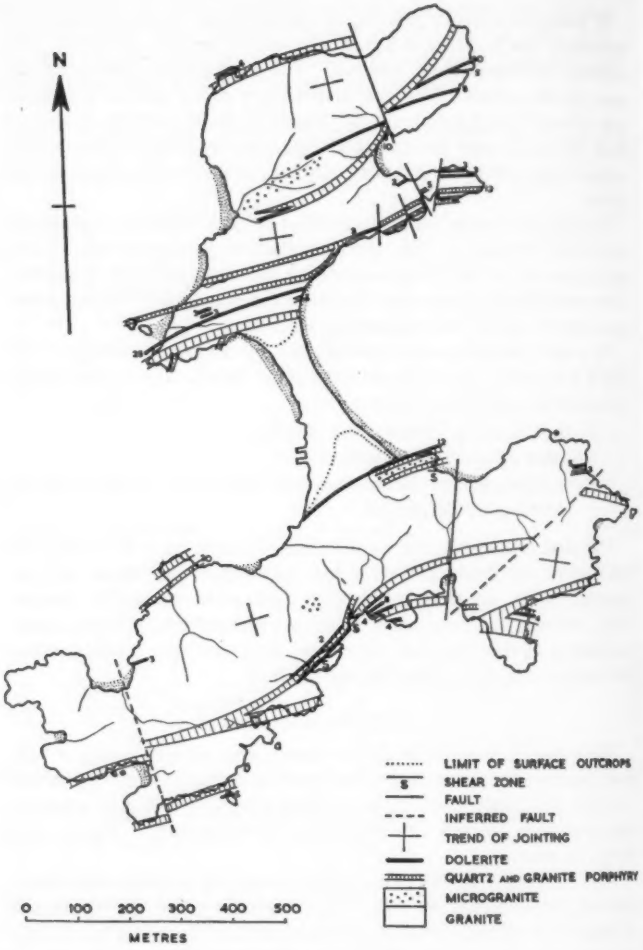
The most interesting structural feature of this island is the northward bending of the dykes just over half way across the island and the complementary southward bending back after some 600 metres. Close examination revealed a multitude of northerly trending faults translating to the north on the eastern side, and the bending is due to a series of complex step-like movements.

(*c*) *Weathering*

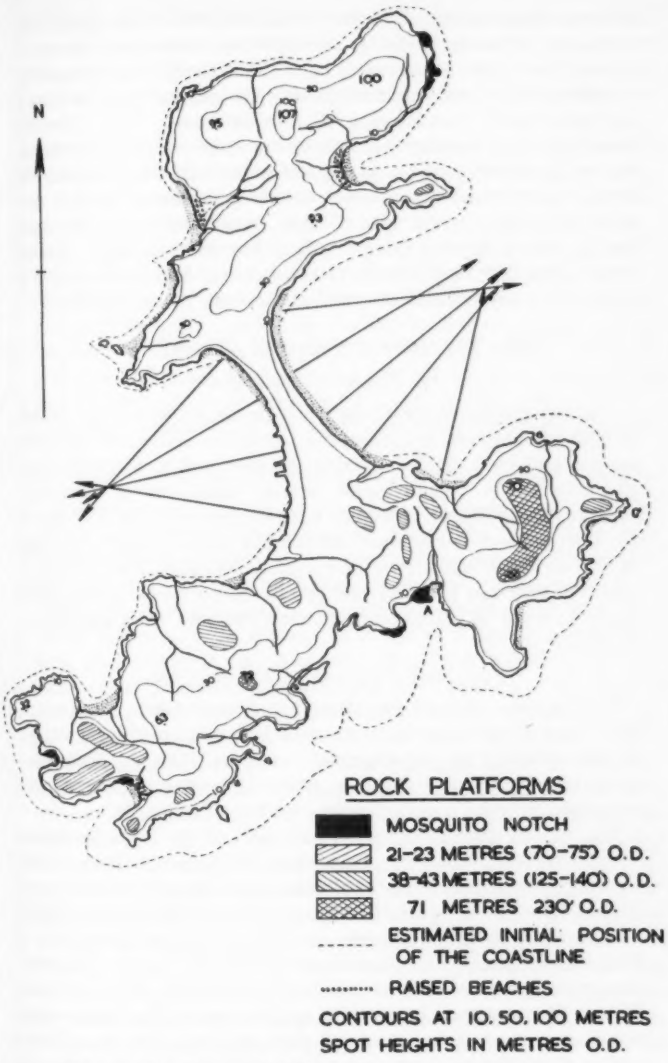
The island is mantled with an uneven coat of weathering debris. Evidence from quarries shows that the weathering profile is up to one hundred feet thick and can be divided into four arbitrary horizons approximately parallel with the surface of the ground. (Ruxton and Berry, in press.)

The lower horizon (IV) of solid rock is variably oxidized with minor residual debris along the major joint planes. Above this dominant rectangular boulders, mantled by sheaths of platy grus, rest in a matrix of subordinate residual debris (Horizon III, Plate VIII, Fig. 2).

This grades upwards into Horizon II of dominant residual debris and subordinate sub-spherical boulders. The debris in Horizons II and III is mostly a silty sand composed of angular quartz and sericitized kaolin lumps, rare bleached biotite and silt, mostly with a granitic texture preserved and of a yellowish or buff colour. The highest



TEXT-FIG. 2.—Geological map of Cheung Chau. Thickness of narrow dykes is given in feet.



TEXT-FIG. 3.—Geomorphological map of Cheung Chau.

Horizon (I) has no granitic texture preserved and is a red clayey sand composed of quartz fragments embedded in a semi-plastic matrix of silt and minor clay; it is variably lateritic and rarely contains boulders.

Most of the island has Horizon II at the surface, some Horizon I on gentle slopes, and Horizon III near the coast. Apart from the instability of the weathering mantle on the steeper slopes, deforestation of the island, followed by cutting and burning of the remaining low scrub, has rendered this mantle even more unstable, and it is now being removed by processes of creep, wash and slump, far more rapidly than it is being formed. Thus the surface is largely covered by a mantle of " lag " gravel and abundant residual boulders, and in places there are gullies and small landslip scars on the hillsides.

III. The Geomorphology of Cheung Chau

(*a*) *General Considerations*

The topography of the Hong Kong region shows features related to both submergence and emergence; drowned valleys indicating the former, and rock platforms, raised beaches and rejuvenated rivers, the latter. The highest raised beaches noted are at 15 metres, but the possibility of a former submergence of over 180 metres has been put forward by Brock (Brock and Schofield 1926). A study of the rock platforms, now in progress, indicates that a bench at about 70 metres is probably marine in origin, so that in the present study a theory of intermittent relative emergence from that level is adopted.

(*b*) *Rock Platforms on Cheung Chau*

The northern part of the island has predominantly steep slopes, but a study of the topography of the south reveals a prominent stepped pattern unrelated to any discernible structural feature. These platforms have been mapped with a Watts 5 in. surveying aneroid, the maximum error for any point being $\pm$ 5 feet (Text-fig. 3).

The summit levels in the south form part of the 71 metres surface noted above, and this part of the island is believed to have evolved from a gently sloping wave-cut platform of which only remnants now remain. During the recession of the sea from this level, there appears to have been halts, or possibly oscillations with stand-stills, for a long enough period for notches and small flats to be developed. Two such groups of surfaces are found on Cheung Chau, between 38 and 43 metres and between 21 to 22 metres. The upper group occurs as a marked accordance of ridge heights in the central area, and as flattenings on spurs, but no sharply defined breaks in slopes have been noted. The 21–22 metres platform is well seen on the south-west of the island where a gently sloping surface on solid granite

is being cut into by vertical cliffs. Inland it terminates at a steep slope running almost north-south across the island, probably representing the position of the old cliff line. An extension of the surface to this position would suggest that it was formed at a mean sea level about 23 m.

Evidence of periods of erosion and deposition in streams in the Colony show that since this bench was cut at least one period of sea level lower than at present intervened, after which it rose to a mean position about 5 metres with a later recession to the modern level.[1] Heanley (personal communication) first recognized the bench formed at this level, and named it the "mosquito notch" from its fresh water pools. It is a common, though discontinuous, feature around Hong Kong coasts and in Cheung Chau is noted at several localities. At A (Text-fig. 3), the notch is 40 to 50 m. wide with a temple, at least 35 years old, built on it. Locally it is found to cut across most of the rock types represented so that suggestions of special processes to account for its formation meet with considerable obstacles.

(c) *Raised Depositional Features—The Tombolo and Raised Beaches*

The tombolo linking the two hard rock masses provides further evidence of a former higher sea level, though the details have been obscured by the growth of a Chinese fishing village of some 18,000 inhabitants across it. The submergence drowned the river valley between the two hills and in the sheltered waters small spits were rapidly built out. The isthmus has a core of decomposed granite at both ends and these determined the position of the tombolo. The shape of the protecting headlands and the directions of the greatest fetch resulted in the prolongation of the southern spit northwards by drift along its western side, and the northern spit southward by drift along its eastern side. With a greater supply of decomposed granite in the north, and the dominant easterly winds (Text-fig. 1), the northern spit was the larger and eventually linked with the smaller southern one. Once the link was complete the tombolo would be widened and strengthened by material drifting along the east side and being swept to the lee by strong storm waves. The protecting peninsulas on either side ensure that the strongest waves affecting the beach pass through a small zone midway between the two headlands. Each of these wave directions has tended to build up the beach at right angles to it, resulting in a curve which approximates to an arc of a circle in the west and to an asymmetrical north-east facing arc on the east (Text-fig. 3).

The tombolo is a feature which allows no detailed estimate of the

[1] Mean sea level is about 1·1 metres (3·76 ft.) O.D., and high spring tides reach 2·5 metres (8·4 ft.) O.D., with a tidal range of about 8 feet. All heights in this paper refer to O.D.

sea level at which it was formed, but the wave-swept material reaches up to 10 m. and it is probably related to " mosquito notch " times. Raised beaches with semi-consolidated material are found in several parts of the island (Text-fig. 3) and have been traced up to 6 metres. It seems likely that the tombolo, the " mosquito notch ", the raised beaches, and the coastal erosion in the south, may be referred to post-glacial times.

(*d*) *The Modern Coast*

Since the sea has attained its present position (including that of " mosquito notch " times), a considerable amount of coastal development has taken place. Deposition is largely related to the tombolo, but around much of the remaining coast erosion has been dominant, and in places considerable retreat has occurred. Cheung Chau is protected from the full force of the China Sea by the Lamma to the east and by Linting and Sam Mun Islands to the south, but under the influence of the dominant easterlies notable wave attack develops from the south and east. Occasionally when typhoons are in the vicinity very heavy storms affect the Colony. Both normal and storm waves are most effective from the south-east, and nearly everywhere, except at the head of a few bays, the southern coast is oversteepened into impressive cliffs. Other parts of the coast show varying degrees of marine erosion, the least modification to the original sub-aerial slopes being on the north-west. A consideration of the various erosional coastal types is significant in assessing the amounts of marine erosion. These are:—

(1) Weathered slopes with only a slight notch at the base, and fronted by a small wave-cut platform in weathered rock.
(2) Steep cliffs of partly weathered rock fronted by an accumulation of angular to sub-rounded boulders on a narrow shore platform.
(3) Steep to vertical cliffs in fresh rock often with a fronting wave ramp, and with deeper water close inshore.

Gradations between these types exist but they each present distinct features.

These forms can be explained with relation to the weathering profiles developed on local granitic rocks. With submergence the initial surface of coastal development was often a weathered slope. The initial slopes on the sheltered north-west were the sides of a former river valley and here we have noted only a small wave-cut notch. Where material has been removed it has been replaced at an almost equal rate by slope wash and creep from above. A more advanced stage in erosion is seen where waves are breaking up the lower weathering horizons (II and III) and the joint blocks, left unsupported by the removal of the weathered debris, accumulate on the foreshore.

Finally, where more extensive retreat has occurred, the sea has cut away the weathered horizons and the cliffs are of fresh rock (Plate VIII, Fig. 1).

If deep weathering is a typical feature of the main rock groups, as in Cheung Chau, coastal types may help to assess the amount of retreat. Naturally these forms may be connected in part with original differences in the weathering profile, or to the removal of some of the weathering horizons during an earlier stage, but on Cheung Chau the close relation between these coastal types and exposure show that they are also a function of the amount of coastal erosion.

Thus in assessing the coastal retreat the factors considered were the truncation of the sub-aerial slopes by wave-cut cliffs; profiles of streams with hanging valleys due to marine erosion; and the weathering horizons removed by erosion. In this way the original form of the island(s) was reconstructed (Text-fig. 3), applying a conservative estimate in each case. The maximum retreat on the south has resulted in a close correlation between the details of the coast and rock structure, while the shores that have suffered minimum retreat show this relationship in a much less pronounced form.

IV. Structural Control on Cheung Chau

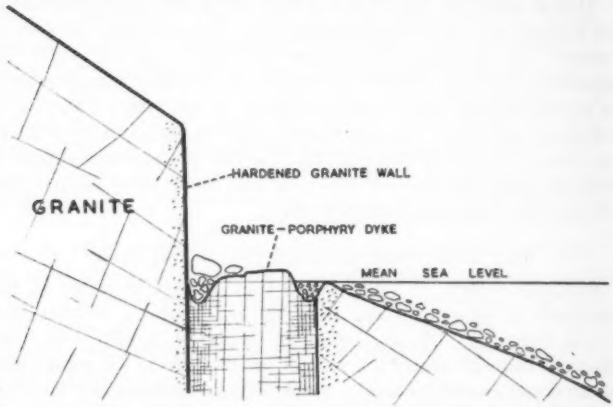
Structural control of landform on the island is indicated in the prevalence of east-north-east trending topographical features and coastal directions. These features are generally parallel with dyke directions and with one of the vertical sets of joints in the granite and are no doubt caused by them. Since only minor features reflect the control of the north-north-westerly joints it appears that the dykes exercise the dominant influence. The general outline of the island is probably due to lines of weakness associated with the dyke directions, and the gap separating the two rock masses may be related to a major structural feature. In the present context we shall confine ourselves to the more detailed relationships exhibited inland and on the coast.

On Cheung Chau the granite-porphyry dykes do not stand out in relation to the granite, as they do on Lan Tau, and this may be due in part to their narrowness, generally less than 100 feet. Yet a considerable part of the coast is margined by these features. A close examination shows the chilled margins of these dykes to be closely jointed, the centre is massively jointed, and the enclosing granite walls are considerably hardened.

If a coastline is highly oblique to a dyke then marine erosion may cut geos in the closely jointed margins, and in a narrow dyke this will result in the centre blocks being removed relatively easily, leaving an inlet with hardened granite walls on either side. In the wider dykes the central portion will be the resistant member, protecting the weaker

selvages, and the granite will be worn back more rapidly. Thus on a " discordant " coast, dykes will prove more resistant, of equal resistance, or weaker than the surrounding granite, depending on their thickness. On Cheung Chau active marine erosion is seldom oblique to the dyke trends, and widths are intermediate, so that coastal features of this type are not well developed.

If the coast is roughly concordant with dyke directions, then although the dyke margins are easily removed, the dyke centres and the hardened granite margins provide a triple barrier to attack. Even on narrow dykes the granite walls still remain a relatively resistant



TEXT-FIG. 4.—Schematic relationship between a typical dyke zone in granite and the mean sea level.

zone (Text-fig. 4). Thus erosion is held up near the dykes and where retreat is active the coast will tend to align itself along dyke directions. But the dykes are broken at many points by oblique lines of weakness such as faults, and these provide avenues where both sub-aerial and marine attack can break through. This has resulted in the stepped coast of south Cheung Chau, the position of the steps being determined by the spacing of the lines of weakness. In the south the main exception to this form of coast is the large bay where the abundance of northerly trending fractures have proved a great aid to erosion. In illustration of the way in which this occurs the coastal section to the north-east is instructive. Four faults each have geos etched out along them. The fault breccias are only about three feet wide but the geos have been extended until they are over 20 yards wide, the largest almost cutting through the headland.

On Cheung Chau the highest land is all of granite and this is not

surprising considering the very minor amount of dyke material on the island. In places the dykes zones stand out slightly in relation to the granite; elsewhere they form depressions, though sometimes there is no effect. Under equal conditions of jointing the granite weathers more rapidly to a silty sand, probably owing to a higher porosity, whereas the granite-porphyry slowly forms a clayey silt which, as a surface mantle, is more resistant to eluviation and erosion.

Unfortunately the land area on Cheung Chau is small, with only a few dykes crossing it, and areas under active erosion are virtually confined to the neighbourhood of the oversteepened coast. Diagnosis is further obscured by the fact that it is difficult to assess the relative role of marine and sub-aerial agencies in the erosion of the area to its present form. Thus a depression along a narrow dyke inland may be a relict of a feature formed by an earlier and higher sea level, and, in fact, a deep chasm along a narrow quartz-porphyry dyke on the south coast stretches inland about fifty metres with vertical walls 45 m. high (Plate VIII, Fig. 1). This is undoubtedly an abandoned geo.

Naturally on wash and other slopes approaching grade there appears to be no topographical expression of geological features, though on the north of the island the dykes show up on aerial photographs, even across such slopes, owing to a denser vegetational cover, which may be due to the more clayey sub-soil.

V. Conclusion

The island of Cheung Chau is in the process of evolution from a drowned landmass with a thick weathering mantle, having hill slopes running smoothly to the sea, to a revived landscape with vertical cliffs cut into fresh unweathered rock, and a coastline showing an intimate control of form by geological structure. Owing to a dominant wave attack from the south-east this evolution has gone furthest on the southern coast where the greatest erosion has occurred, while on the north-west the process has only just begun. In the former the sea has been confronted by a series of roughly parallel dykes normal to the direction of maximum wave attack, which are cut by numerous obliquely trending faults. Retreat has been most rapid along the faults and most retarded along unbroken dyke zones, until recession has produced a stepped-coastline.

The coastline of Cheung Chau presents a serial picture of its own evolution, each segment displaying different characteristics according to its position and structure.

VI. REFERENCES

Brock, R. W., and J. Schofield, 1926. The Geological History and Metallogenetic Epochs of Hong Kong. *3rd Pan-Pac. Congress, Tokyo*, 576–581.

HEANLEY, C. M., 1928. Hong Kong Celts. *Bull. Geol. Soc. China*, vii, Nos. 3 and 4, 209–214.
KUENEN, Ph. H., 1954. Eustatic Changes of Sea Level. *Geol. en mijnbouw*, xvi, 148–155.
LEWIS, W. V., 1938. The Evolution of Shoreline Curves. *Proc. Geol. Assoc*, xlix, 107–126.
RUXTON, B. P., and L. BERRY. Weathering of Granite and associated Erosional Features in Hong Kong. *Bull. Geol. Soc. Am.* (in press).
SCHOFIELD, W., 1920. The Dumb-bell Islands and Peninsulas on the Coast of South China. *Proc. Liverpool Geol. Soc.*, xiii, 45–51.

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EXPLANATION OF PLATE VIII

FIG. 1.—Slope-over-wall cliff on sheet-jointed granite. The south-western headland of Cheung Chau.
FIG. 2.—South Coast of Cheung Chau. Bedrock and mantle of rectangular boulders of Horizon III from which most of the debris has been removed. Note the " mosquito notch " in the foreground and the small notch being formed at the present day.
FIG. 3.—Chasm along composite quartz-porphyry and dolerite dyke on the south coast. The spur on the left rises to 175 feet O.D.

CORRESPONDENCE

FLOW-MARKINGS AND LOAD-CASTS

The Editors regret that the above title was not used as a heading for the letter from Kuenen and Prentice (*Geol. Mag.*, xciv, 173).

Two further manuscripts have been received on the same subject and will be published in due course.

FIG. 1.

FIG. 2.

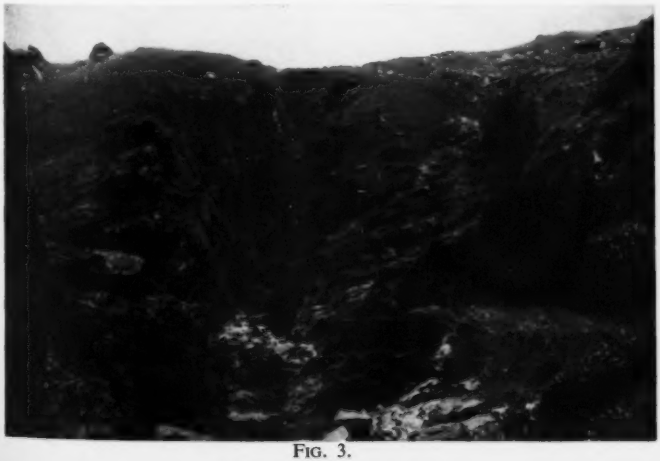

FIG. 3.

CHEUNG CHAU ISLAND.

LINEATION IN COMPLEX FOLD SYSTEMS

SIR,—The emphasis placed by Clifford *et al.* (*Geol. Mag.*, xciv, 1956, pp. 1–24) on the desirability of mapping structures in metamorphic areas on all scales of magnitude may provide an occasion for quoting once again the wise words of Prof. Bruno Sander—" There ought not to be microtectonists and megatectonists working independently of each other, but rather one group of workers investigating the correlations between processes in large and in small units . . . Geology needs petrofabric analysis not less than petrofabric analysis needs geology." As one, however, whose concern for many years has been with the microstructures of rocks (a study of which " microtectonics " forms only one of many aspects, albeit a highly interesting one), I observe with some satisfaction that structural geologists are now reaching fairly general agreement concerning the validity of a relationship between microfabric, lineation, folding, and regional metamorphism in the Moines which I first claimed twenty years ago. When put forward in 1937 this claim rested solely upon a study of the microfabric ; its ultimate acceptance, after widespread doubt and criticism, confirms in a striking manner the soundness of the foundations laid by Prof. Sander and Prof. Schmidt, pioneers whose work has been little appreciated in this country. The history of investigations in the Scottish Highlands scarcely supports the contention of the authors that " it is premature to discuss the significance of the linear structures (or of the microfabric) until one has established the nature of the associated folds ". There has admittedly been much inconsequential argument, mostly between those who have never made a detailed study of the microfabrics in question. But " premature " ? Rather would I assert that the microtectonists have been whole strides ahead of their megatectonist colleagues in being able to demonstrate to them the real significance of the structures which they were mapping, at a time when they themselves were still talking of " north-easterly strike " and " direction of stretching ".

The authors (ibid., p. 23) " dissent from Phillips' view that the regional folding of the Moines occurred about N.W.–S.E. axes " because they have found folds which do not plunge to the south-east. They describe this as being evidence " in flat disagreement " with my deduction. The use of this rather emphatic expression will suggest to most readers that I have made statements about the non-occurrence of folding with other than south-easterly plunging axes. I have done nothing of the kind, and would indeed be quite astonished if, as one penetrated into the heart of the Caledonian range, one *failed* to find folding with Caledonian trend ! What I have done is to draw attention to the evidence (as revealed in the fabric) that *during the early regional metamorphism of a part of the Moines* folding about axes almost at right angles to the Caledonoid trend developed as an important and widespread structure. The suggested correlation with pre-Torridonian folding in the Foreland, made tempting by the coincidence of direction across the marginal fracture zone (a coincidence found also on the opposite flank), is weakened as developing knowledge of folding within the Caledonides demonstrates relationships of the kind described by the authors. Possibly it may ultimately have to be abandoned, but I shall watch with interest the unfolding of the final structural synthesis which will accommodate that eventuality.

REFERENCE

SANDER, B., 1934. Petrofabrics (Gefügekunde der Gesteine) and Orogenesis. *Amer. Journ. Sci.*, ccvii, 37–50.

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REVIEWS

STRUCTURAL GEOLOGY FOR PETROLEUM GEOLOGISTS. By W. L. RUSSELL. x + 427 pp., with 149 text-figs. McGraw Hill, New York and London, 1955. Price 56*s*. 6*d*.

This is a straightforward book comprising many of the essential features of any similar sized book on structural geology orientated for the intending petroleum geologist. There is an early chapter on maps and cross-sections and a final collection of laboratory problems which give it practical emphasis, but throughout the author has wisely attempted to make it a general rather than a specialized work, and so it must be compared with several other books on structural geology. Reference is facilitated by a sub-division into headed paragraphs each giving a simple definition and exposition of the topic. There is a considerable range of topics listed and each chapter is supported by a very full bibliography.

Unfortunately what promises to be an invaluable elementary reference work is marred by a lack of critical examination of much that has been compiled, so that many definitions may add to, rather than clarify, the present terminological as well as conceptional confusions. The book could have been very much shorter if more had been left to the imagination, thus: "What is here called theory consists in listening to lectures and reading books and periodicals on structural subjects," or "The orientation is generally given by an arrow pointing north, and north is generally at the top. However, if the shape of the map makes it inconvenient to place north at the top, it is permissible to depart from this custom".

W. B. H.

MICROSCOPIC PETROGRAPHY. By E. WILLIAM HEINRICH. pp. viii + 296, 70 text-figs. New York (McGraw Hill), 1956. Price 49*s*.

PETROGRAPHIC MINERALOGY. By ERNEST E. WAHLSTROM. pp. vii + 408 (with 30 tables, 173 text-figs., 1 coloured plate). New York (Wiley), London (Chapman and Hall), 1955. Price 63*s*.

From their titles it might be thought that these two books would cover the same ground but their fields are really complementary. While Wahlstrom's book attempts to cover the gap between existing texts on crystal optics and those which deal with systematic petrography, Heinrich's work is closer to a standard type of petrography of the igneous, sedimentary, and metamorphic rocks.

The purpose of *Petrographic Mineralogy* is to show the methods whereby an elementary student with some knowledge of crystal optics, by examining a rock slice with the petrographic microscope, may first recognize the mineral constituents correctly and then identify and classify the rock. The book may be divided into three parts. The first part (91 pages) outlines very briefly the collection and preparation of samples and the principles of mineral separation. There is a good chapter on the microscopic examination of minerals and aggregates which places special emphasis on the determination of optical orientations. Other subjects introduced are the basic procedures for using the universal stage and the graphical presentation of chemical data for rocks, including the procedure, and tables for calculating the C.I.P.W. norm.

The second part (193 pages) is one of the best available systematic treatments of the optical properties of the rock-forming silicate and non-silicate minerals. The use of accurately determined optical properties is emphasized again and the text is supported by numerous easily read optics—composition diagrams, microphotographs, and clear line drawings of important habits of many of the minerals showing the orientation of the indicatrix.

The final sections (107 pages), are devoted to the recognition, description, and classification of igneous, sedimentary, and metamorphic rocks. The igneous and sedimentary chapters are clearly written and enable the rock

to be classified by integrating optical mineral determinations with textural and structural features: additional microphotographs of textures would have improved this section. The final chapter on metamorphic rocks is by far the weakest in the whole book. In adopting a structural approach the author has failed to make any adequate reference to the chemical or mineralogical nature of the original rocks or to the conception of grade in metamorphism.

Heinrich's *Petrography* is nicely bound and clearly written; the petrographic treatment of the igneous and sedimentary rocks follows the standard American pattern. A wealth of petrographic information is provided but in the igneous section the occurrence of rare types, e.g. those containing barian feldspars, is given undue emphasis and no clue is provided as to where the descriptions of such rocks can be found. No distinction is made between quartz and alkali dolerites or between alkali and tholeiitic basalts. In the metamorphic section the concepts of grade, of metamorphism as a progressive process, and of metamorphic facies are condensed to two pages and the classification, based on mineralogical groupings, appears too unnatural and unwieldy to enable an intermediate student to develop a comprehensive picture of metamorphic rocks.

The absence of a detailed bibliography, the small size of many of the microphotographs, and the omission of a classification chart for the igneous rocks are additional features which have prevented this book from being so much better. These features, it is to be hoped, will be rectified in a second edition.

I. D. M.

PUBLICATIONS RECEIVED

GEOLOGICAL SURVEY OF GT. BRITAIN, *Bulletin* No. 12. Papers by G. S. JOHNSTONE and J. E. WRIGHT; R. C. TOMLINSON; A. H. V. SMITH and R. W. WILLIAMS; G. A. GOODLET; M. A. CALVER. pp. iv + 86, with figs., tables, and plate. London, H.M.S.O., 1957. Price 8*s.* 6*d.*

GEOLOGICAL SURVEY OF GT. BRITAIN. Memoirs of the Geological Survey. *The Limestones of Scotland.* By Dr. A. MUIR, Dr. H. G. M. HARDIE, Dr. R. L. MITCHELL, and Dr. J. PHEMISTER. pp. iv + 150, with tables and 4 plates. London, H.M.S.O., 1956. Price £1 1*s.*

GEOLOGICAL SURVEY OF GT. BRITAIN. *Coalfield Papers No.* 1. The Economic Geology of the Stirling and Clackmannan Coalfield, Scotland. Area North of the River Forth. By E. H. FRANCIS, with Palaeontology by M. A. CALVER and R. B. WILSON. pp. vi + 36, 13 figs., 2 tables (8½ × 13 inches mimeographed). Edinburgh, H.M.S.O., 1956. Price 5*s.*

F. DIXEY. *The East African Rift System.* Colonial Geology and Mineral Resources Supplement Series. Bulletin Supplement No. 1. pp. 71, 15 text-figs., 7 plates. London, H.M.S.O., 1956. Price 7*s.* 6*d.*

NIGERIA. *Records of the Geological Survey of Nigeria*, 1954. pp. 40, pl. 4, 3 maps. Crown Agents for Oversea Governments, Millbank, London, 1956. Price 4*s.* 6*d.*

NIGERIA. *Annual Report of the Geological Survey Department for the year* 1955–6. pp. 15. Federal Government Printer, Lagos, 1957. Price 9*d.*

SOUTH AFRICA. Geological Survey, Special Publication No. 15. *The Geology of the Barberton Area.* Compiled by D. J. L. VISSER. pp. xiv + 253, 14 figs, 45 pls., with coloured map (1 : 50,000) in four sheets. Price £1 15*s.*

PERU. Boletin de la Sociedad Geologica del Peru. Tomo 28. *Geologia de la Carretera Huancayo-Santa Beatriz en el Peru Central.* By JOHN V. HARRISON. pp. 47 and map. Lima, 1956.

POLAND. *Annales de la Société Géologique de Pologne.* Vol. XXIV, fasc. 4. Krakow, 1956. pp. 409–471, 6 figs, 2 tables. Vol. XXV, fasc. 1. Krakow, 1956. pp. 1–102, figs. and tables. Vol. XXV, fasc. 2. Krakow, 1956. pp. 105–158, figs. and plates.

GEOLOGY OF URANIUM AND THORIUM. *Peaceful Uses of Atomic Energy: Proceedings of the International Conference in Geneva*, 1955, *Volume* 6. pp. × 825, 4to. Price 63*s*. United Nations ; available from H.M.S.O., P.O. Box 569, London, S.E. 1.

CANADA. The Royal Society of Canada Special Publications, No. 1. *The Grenville Problem*. Edited by James E. Thomson. pp. viii + 119 figs. and tables. Toronto University Press (London, Oxford University Press), 1957. Price 31*s*. 6*d*.

J. C. JAEGER. *Elasticity, Fracture and Flow* (with Engineering and Geological Applications). pp. viii + 152, 54 diagrams. Methuen and Co., Ltd. (Monographs on Physical Subjects.) London, 1956. Price 10*s*. 6*d*.

A. K. LOBECK. *Things Maps Don't Tell Us*. pp. x + 159, 72 diagrams. The MacMillan Co., New York and London, 1956. Price 34*s*. 6*d*.

H. PEAKE and H. J. FLEURE. *Times and Places* (Corridors of Time, x). pp. xv + 336, 76 figs. Clarendon Press, Oxford, 1956. Price 42*s*.

C. J. W. SIMPSON. *North Ice. The Story of the British North Greenland Expedition*. pp. 384, 57 illustrations, 6 maps and plans. Hodder and Stoughton, Ltd., London, 1957. Price 37*s*. 6*d*.

S. W. WOOLDRIDGE and G. E. HUTCHINGS. *London's Countryside*. pp. xiv + 223, 4 plates, 36 maps and diagrams. Methuen and Co., London, 1957. Price 18*s*. 6*d*.

S. W. WOOLDRIDGE. *The Geographer as Scientist*. pp. xii + 299, 30 maps and diagrams. Thomas Nelson and Sons, Ltd., Edinburgh, 1956. Price 35*s*.

Ministry of Housing and Local Government (Dept. of Health for Scotland) in collaboration with the Geological Survey of Great Britain. LIMESTONE: *map* (scale 1 : 625,000) showing geological horizons of economic limestone (including dolomite) with output (1949) and uses of material produced by individual quarries and mines. 1957. Map price 5*s*. for each sheet (Scotland, and England and Wales), with text price 9*d*., from Ordnance Survey Agents.

SOUTH AFRICA. *Geological Map of the Union of South Africa*, in four sheets, on a scale of 1 : 1,000,000. Geological Survey of S. Africa (L.T. Nel, Director), 1955.